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Adsorption, Condensation, and Absorption Devices

IT Enviroscience
Knoxville, TN

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EPA is developing new source performance standards under Section 111 of the Clean Air Act and national emission standards for hazardous air pollutants under Section 112 for volatile organic compound emissions (VOC) from organic chemical manufacturing facilities. In support of this effort, data were gathered on chemical processing routes, VOC emissions, control techniques, control costs, and environmental impacts resulting from control. These data have been analyzed and assimilated into the ten volumes comprising this report.

This volume covers the following devices that can be used to control VOC emissions: carbon adsorbers, condensers, and absorbers.

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Volume 5: Adsorption, Condensation, and Absorption Devices

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

December 1980

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INTRODUCTION

A. SOCMI PROGRAM

Concern over widespread violation of the national ambient air quality standard for ozone (formerly photochemical oxidants) and over the presence of a number of toxic and potentially toxic chemicals in the atmosphere led the Environmental Protection Agency to initiate standards development programs for the control of volatile organic compound (VOC) emissions. The program goals were to reduce emissions through three mechanisms: (1) publication of Control Techniques Guidelines to be used by state and local air pollution control agencies in developing and revising regulations for existing sources; (2) promulgation of New Source Performance Standards according to Section 111(b) of the Clean Air Act; and (3) promulgation, as appropriate, of National Emission Standards for Hazardous Air Pollutants under Section 112 of the Clean Air Act. Most of the effort was to center on the development of New Source Performance Standards.

One program in particular focused on the synthetic organic chemical manufacturing industry (SOCMI), that is, the industry consisting of those facilities primarily producing basic and intermediate organics from petroleum feedstock meterials. The potentially broad program scope was reduced by concentrating on the production of the nearly 400 higher volume, higher volatility chemicals estimated to account for a great majority of overall industry emissions. EPA anticipated developing generic regulations, applicable across chemical and process lines, since it would be practically impossible to develop separate regulations for 400 chemicals within a reasonable time frame.

To handle the considerable task of gathering, assembling, and analyzing data to support standards for this diverse and complex industry, EPA solicited the technical assistance of IT Enviroscience, Inc., of Knoxville, Tennessee (EPA Contract No. 68-02-2577). IT Enviroscience was asked to investigate emissions and emission controls for a wide range of important organic chemicals. Their efforts focused on the four major chemical plant emission areas: process vents, storage tanks, fugitive sources, and secondary sources (i.e., liquid, solid, and aqueous waste treatment facilities that can emit VOC).

B. REPORTS

To develop reasonable support for regulations, IT Enviroscience gathered data on about 150 major chemicals and studied in-depth the manufacture of about 40 chemical products and product families. These chemicals were chosen considering their total VOC emissions from production, the potential toxicity of emissions, and to encompass the significant unit processes and operations used by the industry. From the in-depth studies and related investigations, IT Enviroscience prepared 53 individual reports that were assembled into 10 volumes. These ten volumes are listed below:

Volume 1 : Study Summary
Volume 2 : Process Sources
Volume 3 : Storage, Fugitive, and Secondary Sources
Volume 4 : Combustion Control Devices
Volume 5 : Adsorption, Condensation, and Absorption Devices
Volume 6-10: Selected Processes

Volumes 4 and 5 are dedicated to the evaluation of control devices used as add-on controls to reduce VOC emissions. These add-on controls are discussed generally in Volumes 2 and 3 as emission control options for the control of VOC emissions from generic sources. The use of these add-on controls in specific applications is demonstrated in the process studies covered in Volumes 6 through 10.

This volume covers the application of carbon adsorption, gas absorption, and condensation as add-on VOC emission control devices. These reports discuss the practical use of each control device, describe the systems, and discuss key design considerations. Data, tables, and curves are presented to enable preliminary cost and energy impacts to be determined for a wide range of potential applications. These control device evaluation reports were used to develop the cost effectiveness and energy impact determinations presented in the process reports of Volumes 6 through 10. The focus of these reports is on control of new sources rather than on existing sources in keeping with the main program objective of developing new source performance standards for the industry. The reports do not outline regulations and are not intended for that purpose, but they do provide a data base for regulation development by the EPA.

REPORT 1

CONTROL DEVICE EVALUATION
CARBON ADSORPTION

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I. INTRODUCTION

Vapor-phase carbon adsorption is currently used by many industries as an emission control or solvent recovery technique.[1]* As a control technique for volatile organic compound (VOC) emissions it can be used on waste-gas streams of low VOC concentration when such devices as condensers or scrubbers are ineffective or uneconomical. The main function of a vapor-phase carbon adsorption system is to contain and concentrate the dilute organic vapors. Once the organics are in a concentrated form, they can be recovered or disposed of.

Carbon adsorption is usually a batch operation involving two main steps, adsorption and regeneration. The system usually includes multiple beds so that at least one bed is adsorbing the organics from the gas stream while at least one other bed is being regenerated, thereby ensuring that the emissions will be continually controlled. The system shown in Fig. I-1 is a typical fixed-bed carbon adsorption system that uses steam to regenerate the spent beds. A blower is usually required to overcome the pressure drop across the carbon bed. The VOC-laden gas is passed down through the fixed carbon bed and the cleaned gas is exhausted to the atmosphere. When the VOC concentration of the exhausted gas starts to increase from its baseline effluent concentration level, that bed is shut off and the VOC-laden gas is routed to another carbon bed. The amount of material adsorbed per unit weight of carbon is called the operating capacity.

The spent carbon bed is usually regenerated with low-pressure steam that is passed up through the bed. The steam and VOC vapors leaving the bed are condensed, and VOC is separated from the water by decantation or distillation. After regeneration the carbon bed is cooled and dried to improve adsorption.

This report deals mainly with the design and cost of a fixed-bed adsorber with steam regeneration. However, there are alternative designs for carbon adsorption systems, such as those making use of hot inert gas or vacuum regeneration instead of steam regeneration and those employing fluidized instead of fixed carbon beds. The alternative designs are briefly discussed in Sect. II.

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*See Sect. VII for references cited in this report.

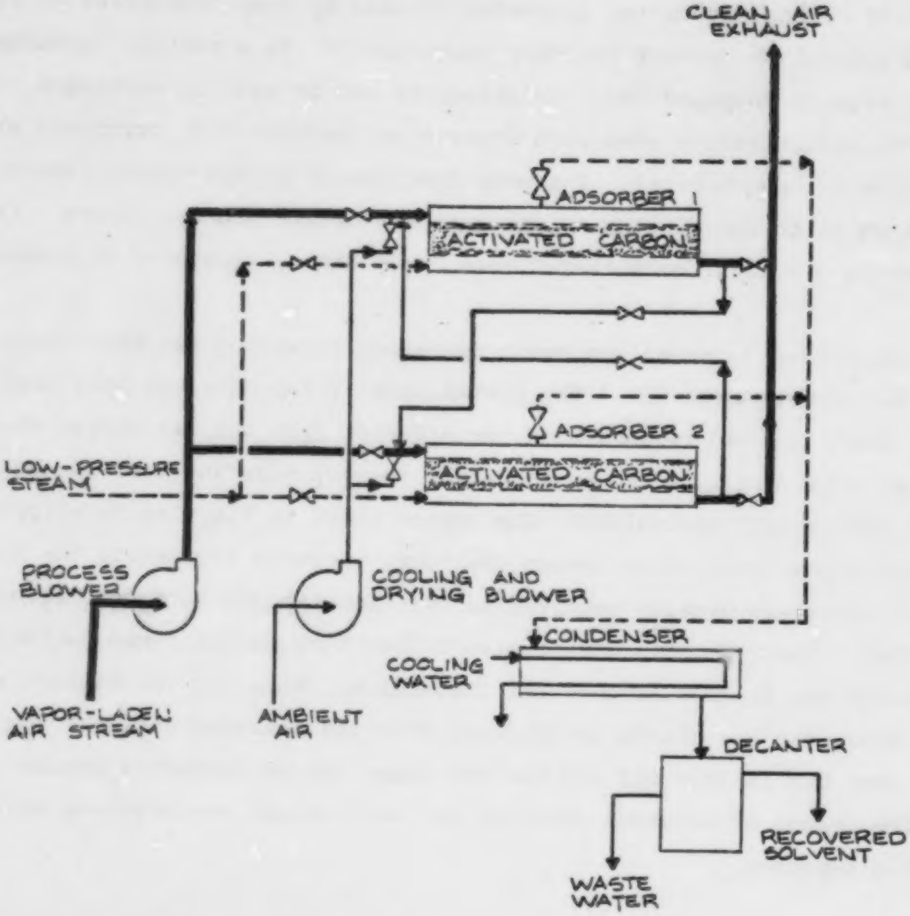

CLEAN AIR
EXHAUST
ADSORBER 1
ACTIVATED CARBON
ADSORBER 2
ACTIVATED CARBON
LOW-PRESSURE
STEAM
PROCESS
BLOWER
COOLING AND
DRYING BLOWER
CONDENSER
COOLING
WATER
VAPOR-LADEN
AIR STREAM
AMBIENT
AIR
DECANTER
RECOVERED
SOLVENT
WASTE
WATER

Fig. I-1. Activated-Carbon Adsorption System

Carbon adsorption for control of VOC gas streams has several limitations. The gas entering the adsorber must be free of particles or liquid; particles in the feed gas would build up on the bed surface and cause an excessive pressure drop across the adsorber. Liquid in the feed gas may cause excessive temperature increases in the carbon bed due to heat of adsorption. Liquids and solids may cause loss of efficiency by blocking adsorption sites. If the feed gas contains particulates or liquid, it must be pretreated. Humidity control will be necessary for feed gas streams that have above 50% relative humidity so that the water vapors will not affect the adsorption capacity of the carbon.

The inlet VOC concentrations may be limited to comply with insurance codes requiring that the concentration be maintained below some percent of the lower explosion limit (LEL) or to prevent the possibility of temperature increases due to the heat of adsorption.

Since carbon is a very good insulator, undissipated heat may cause hot spots to develop, and a condenser may have to be used to remove those VOC with high boiling points. Dilution air may also be added to reduce the VOC concentration.

The adsorption and regeneration limitations of a carbon system prohibit the effective control of many VOC by carbon adsorption. For example, very low molecular weight VOC do not adsorb well on carbon and very high molecular weight compounds are difficult to remove during regeneration.

The temperature of the feed-gas stream should be below 100°F. Lower temperatures give higher operating capacities if the gas stream is dry. However, if moisture is present, lower temperatures give higher relative humidities and these higher humidities can decrease operating capacities. This decrease becomes pronounced at relative humidities of over 50%. The optimum feed-gas temperature must therefore be determined on a case-by-case basis.

II. CARBON ADSORPTION SYSTEMS AND FACTORS INFLUENCING PERFORMANCE AND DESIGN

In this section the main elements of a carbon adsorption system are discussed and factors influencing system design and performance are analyzed. The analysis is directed toward development of a design for a typical or base-case adsorption system. It is this base-case system and variations of it that form the basis for the cost estimation given in Sect. IV.

Fixed-bed adsorption with steam regeneration is the only system examined in depth here. This system includes carbon beds, blowers, condenser, condensate decanter, piping, valves, and instrumentation. For some carbon systems, however, additional equipment may be required for pretreatment of the gas stream or for additional treatment of the VOC recovered during regeneration. These considerations are briefly discussed but design and cost details are not presented. Fluid-bed adsorption systems are also mentioned but not analyzed.

A. FIXED-BED ADSORPTION

1. Pretreatment

A VOC emission stream may have to be treated before it can be sent to the carbon adsorber. Stream conditions or contaminants that adversely affect carbon adsorber performance are excessively high temperatures, high humidity, entrained solids, entrained liquids, and high-boiling organics. The effect and subsequent additional cost of these conditions or contaminants on a particular carbon adsorption system must be dealt with for each individual application. The various types of inlet-stream conditions or contaminants that might be encountered are discussed and the steps that might be required to deal with the situation are outlined.

a. Temperature——The adsorption capacity of the carbon and the effluent concentration of the adsorber are directly related to the temperature of the inlet stream to the adsorber. Normally the temperature of the inlet stream should be below 100°F or else the adsorption capacity will be affected. Inlet-stream coolers are normally required when the waste-gas temperatures are in excess of 100°F. Water-cooled finned-tube types of heat exchangers are usually provided to cool the inlet stream. Costs associated with cooling the inlet stream depend on the inlet temperature, flow rate, and temperature of the cooling water available.

b. Humidity——Relative humidities greater than 50% can have a significant effect on the operating capacity of carbon. The effect of relative humidity on the system should be dealt with for each individual application, but systems in which the relative humidity approaches 100% will require additional equipment to reduce the water content. The equipment required for humidity control is usually a series of coolers (to remove water) and reheaters. However, a single heater could be used if the temperature of the inlet stream is significantly low, and the increase in temperature will not greatly affect adsorption efficiency. Another alternative to decrease the relative humidity of a stream is to add dilution air to the system. This method will work if the dilution-air humidity is significantly less than the inlet stream humidity. Adding dilution air will increase the size and thus the cost of the adsorber required. The installed cost of humidity control by a series of heaters and coolers or a single heater will be $1/cfm to $2/cfm for a 5000-scfm carbon adsorption unit.

c. Entrained Solids——Entrained solids such as airborne dust, lint, and other general particulates may cause the carbon bed to plug over a period of time. The particulates that could affect adsorption performance are usually controlled by a cloth or fiberglass filter. Depending on the application, either a simple throw-away filter or a fabric filter can be used. A throw-away type of filter costs in the range of $100/1000 cfm. Information on fabric filters can be found in ref 2, and cost data can be found in ref 3. Electrostatic precipitators are not usually reocmmended for pretreatment of carbon adsorption inlet streams, because there is a possible safety problem of electric arc in the duct with organic vapors in the explosive range. Normally the inlet stream concentration to the adsorption unit is less than 25% of the LEL but upsets could cause the concentration to rise into the LEL range.

d. Entrained Liquids——Entrained liquids can cause operational problems for carbon adsorption. If the entrained liquid is water, it should be removed for the same reason discussed for relatively humidity. If the entrained liquid is a volatile organic, it will also consume adsorption capacity needlessly. A number of mist eliminators are available, and one should be used if this problem exists. For droplets greater than 5 to 10 μm in diameter a cyclone or zigzag baffle can be used, which, if properly designed, will result in efficiencies of greater than 95%. To control droplets in the 1- to 5-μm range a small-mesh screen would be required. For droplets less than 1 μm a packed filter device would be necessary. A packed filter device has a high pressure drop (15 to 20 in. H_2O) compared to the pressure drop (less than 1 in. H_2O) across the cyclone or zigzag baffle or the screen. For further information on mist eliminators refer to ref 4. The cost of a mesh-type mist eliminator is in the range of $150/1000 cfm.

e. High Boilers——A high percentage of high boilers in the off-gas feed stream will be adsorbed on the carbon and will not be removed during steam regeneration. This constant buildup of high boilers remaining on the carbon will greatly reduce the operating capacity and will require frequent replacement of the carbon. Also, plasticizers or resins should be prevented from entering the carbon bed since they may react chemically on the carbon to form a solid that cannot be removed from the bed during steaming. To prevent frequent replacement of the carbon a condenser may be necessary to reduce the high-boiler concentration. If the high boilers are in the form of entrained liquids, such as oil droplets, a mist eliminator will reduce the buildup. If the high boilers cannot be removed from the inlet stream to the adsorber, a carbon guard bed in the adsorber may result in less carbon being replaced periodically. The guard bed would be considered as a sacrificial device and would be replaced more often than the entire bed.

2. Adsorption

Defining the VOC content and the operating capacity as explained below will reduce the number of variables required to cover the necessary range of flows, concentrations, and VOC molecular weights and will simplify the presentation of cost and environmental impacts.

a. VOC Content——In this study the VOC content of the gas to be treated is defined in the units of lb of VOC/1000 scf. The conversion from ppm (volume) can be made by using the first part of Fig. II-1 or by the following relationship:

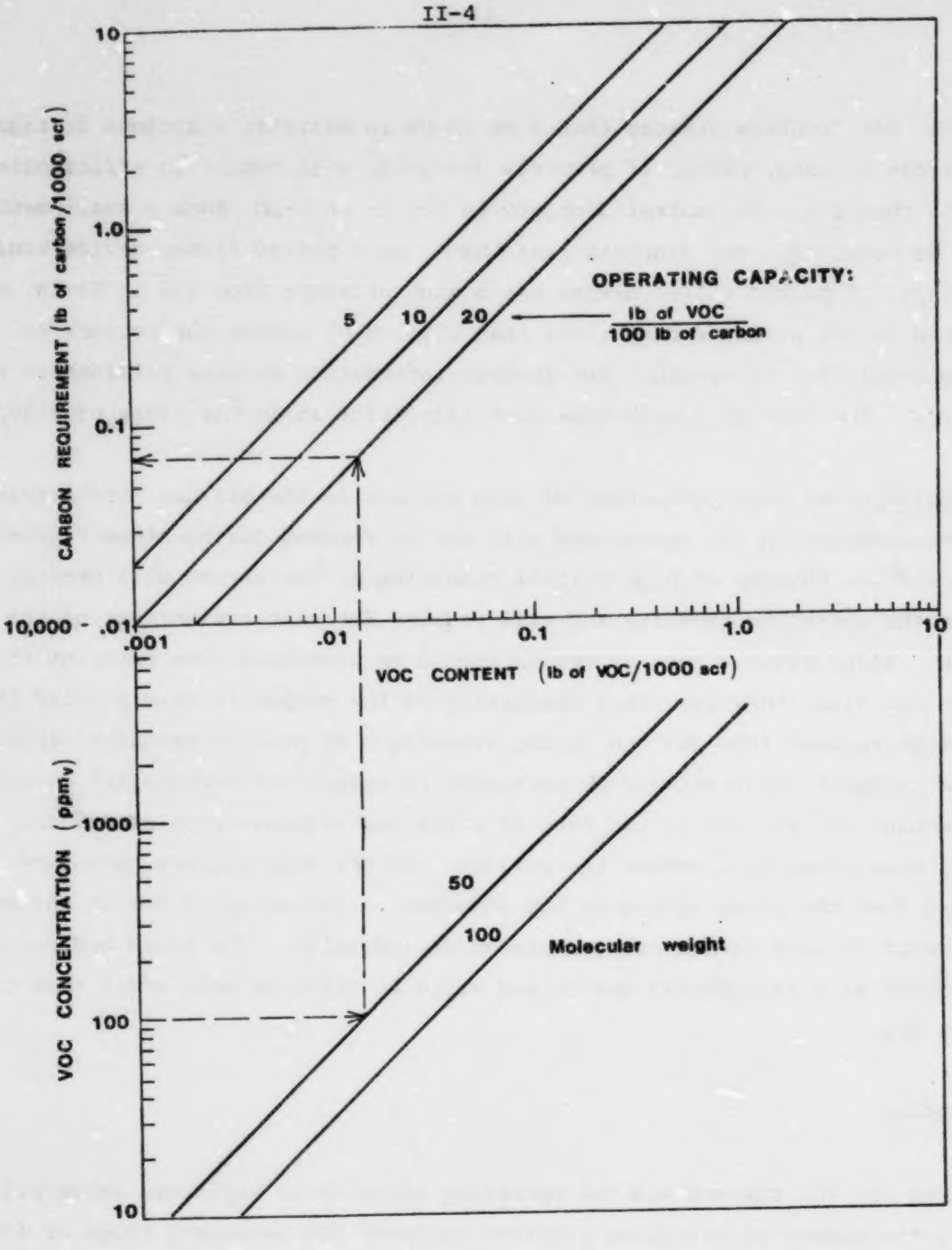


Fig. II-1. Nomograph for Determining Carbon Requirement

$$\text{lb of VOC/1000 scf} = \frac{\text{ppm}_v \text{ X VOC molecular weight (lb/lb-mole)}}{359 \text{ X } 1000} .$$

b. Operating Capacity—The determination of the actual operating capacity (also commonly referred to as working capacity) of carbon is considered to be beyond the scope of this study, since it is affected by a multitude of factors. These factors include the properties of the carbon, the properties of the feed stream, such as humidity and multiple components, and the percent of containment that must be removed. Consideration of the theoretical aspects can be found in the literature.[5—12] For the purpose of this study it is assumed that for a particular VOC feed stream the operating capacity can be determined from operating industrial units, carbon manufacturers, carbon equipment vendors, or pilot-plant studies. Pilot tests should be continued through enough cycles to determine the residual constant VOC. It is important that the operating capacity used includes all the factors that occur in actual practice and for each specific case that the operating capacity is considered to be less than the saturated adsorption capacity that may be reported. (Some reported operating capacities are shown in Table II-1.)

c. Carbon Requirement—Carbon requirement in this study is defined as lb of carbon/1000 scf and is a function of the VOC content of the gas to be treated and the operating capacity of the carbon:

$$\text{Carbon requirement } \frac{\text{lb of carbon}}{\text{1000 scf}} = \frac{\text{VOC content (lb of VOC/1000 scf) X 100}}{\text{operating capacity (lb of VOC/100 lb carbon)}} .$$

Figure II-1 is a nomograph for determining the carbon requirement for systems with a variety of VOC concentrations, molecular weights, and operating capacities. Systems with high VOC operating capacities per lb of carbon and high concentrations of VOC in the process waste gas can have the same carbon requirement as systems with low VOC operating capacities per lb of carbon and low concentrations of VOC in the waste gas.

In this study costs were determined for nine different carbon requirements, ranging from 0.1 to 10.0 lb of carbon/1000 scf.

Table II-1. Important Properties for Design of Adsorption System for Selected Organics

Compound	Boiling Point[a] (°F)	Liquid Molar Volume[a] (cm^3/mole)	Lower Explosion Limit[a] (ppm)	Reported Operating Capacity[b] (lb/100 lb of carbon)
Benzene	176	95	14,000	6
Butyl acetate	260	152	14,000	8
n-Butyl alcohol	210	105	17,000	8
Cyclohexane	178	118	13,000	6
Ethyl acetate	171	106	25,000	8
Ethyl alcohol	173	61	33,000	8
Heptane	208	163	12,000	6
Hexane	154	140	13,000	6
Isopropyl acetate	199	129	18,000	8
Methyl acetate	135	83	31,000	7
Methyl alcohol	149	42	60,000	7
Toluene	231	118	14,000	7
Trichlorotrifluoroethane	118	120		8
Xylene	291	140	10,000	10

[a] See ref 7.

[b] See ref 12. Capacities are for relatively dry compounds (or simple mixtures of compounds) that are particulate-free at 100°F. The effluent concentration achievable with these capacities is not reported.

d. Flow Rate (of Gas To Be Treated)——In this study base-case costs were determined for six different flow rates, ranging from 300 to 100,000 scfm.

e. Temperature——The feed-gas temperature is assumed to be 100°F for the base case. Carbon adsorption units operate most effectively in the temperature range of 60 to 130°F. Most current carbon adsorption units are operated at 75 to 100°F, with a few units being operated at 60°F and a few as high as 200°F. Increase or decrease of temperature within the range of 90 to 110°F will have little effect on adsorption.

f. Gas Velocity (Superficial)——Linear velocities of 50 to 100 fpm are normally used in bed designs. At higher velocities the bed pressure drop becomes too high for standard blowers. At lower velocities the bed becomes too large and expensive. If inlet concentrations are low (as is expected in the SOCMI industry), the bed area required for the volume of carbon needed usually permits a velocity at the high end of this range. Therefore a superficial velocity of 100 fpm is used in the base case.

g. Bed Depth——Fixed-bed carbon adsorption systems normally have bed depths of 1.5 to 3 ft, although under certain conditions the depth may be as small as a few inches. The minimum bed depth of 1.5 ft is assigned for the adsorption zone. The maximum bed depth of 3 ft is considered to be reasonable with regard to the pressure developed by standard blowers.

The difference in capital cost between a 1.5-ft-deep bed and a 3-ft-deep bed arises from the cost of the additional carbon and the larger-pressure-drop blower. The carbon bed containers are usually large enough for the extra 1.5 ft to be added to the bed at minimal cost, and therefore there is little capital cost difference between the 1.5-ft bed and the 3.0-ft bed. Since the incremental cost of adding more carbon to a large vessel is more than offset by the added flexibility that a longer adsorption cycle gives, a bed depth of 3 ft is used in the base case.

h. Pressure Drop——The pressure of the feed gas will affect the design of the system in terms of the power requirements of the blower. A pressure drop of 2.5 to 10 in. H_2O/ft of carbon bed is normally experienced with a flow velocity of 50 to 100 fpm through the carbon bed. If the feed-gas pressure is high enough to permit a reasonable superficial velocity, then no blower is required. The base-case system is assumed to require a blower to develop the necessary pressure.

The base-case adsorber uses 4 X 10 mesh BPL carbon, which at the base case velocity of 100 fpm has a pressure drop of 6.5 in. H_2O/ft of carbon bed. With the base-case bed depth of 3 ft the total pressure drop is 19.5 in. H_2O. (Bed pressure drop vs superficial velocity for two different BPL carbons is shown in Fig. II-2.) This differential pressure can be developed efficiently by standard blowers.

i. Loading Time (per Bed)——Loading time is calculated from bed depth, carbon density, gas velocity (superficial), and carbon requirement:

loading time (hr) =

$$\frac{\text{bed depth (ft) X density (lb/ft}^3\text{) X 1000}}{\text{velocity (fpm) X 60 (min/hr) X carbon required (lb/1000 ft}^3\text{)}} .$$

Figure II-3 shows the loading time for various carbon requirements and bed depths for a bed with a carbon density of 30 lb/ft^3 and a superficial gas velocity of 100 fpm.

j. Bed Area and Pounds of Carbon (per Bed)——The bed area (per bed) is calculated by dividing the flow rate (scfm) by the superficial gas velocity through the bed (for the base-case, 100 fpm). The pounds of carbon (per bed) are most conveniently determined by calculating the bed volume and multiplying by the bed density. In the base case the bed depth is 3 ft and the bed density is 30 lb/ft^3:

bed area (ft^2) = flow rate (acfm)/gas velocity (ppm).
carbon (lb) = bed area (ft^2) X bed depth (ft) X bed density (lb/ft^3).

k. Minimum Cycle Time——The minimum cycle time for the system is normally dependent on the time required to regenerate, dry, and cool the bed. Steam regeneration rates are typically 0.5 to 1 (lb of steam/min)/ft^2 but can be as high as 4 (lb

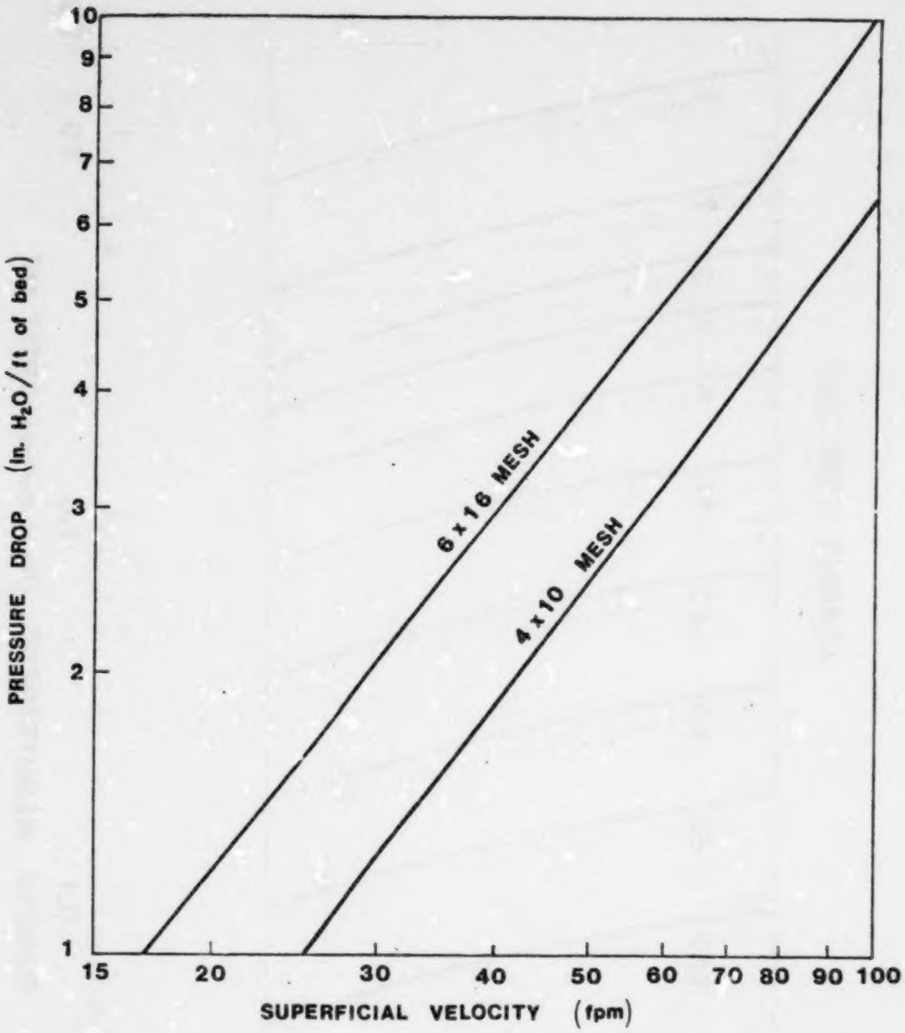


Fig. II-2. Bed Pressure Drop for BPL Carbon

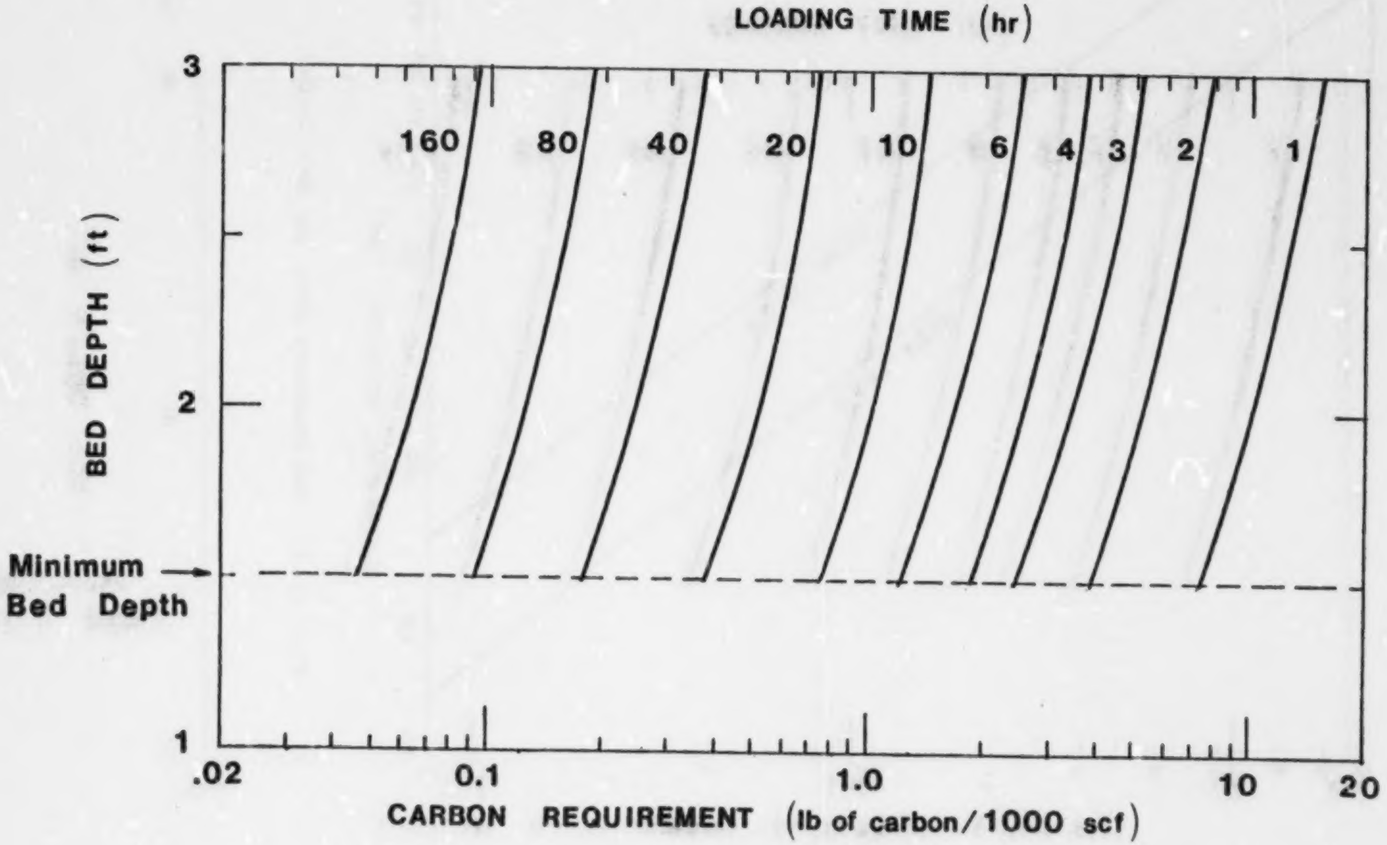


Fig. II-3. Loading Time for Various Carbon Requirements and Bed Depths at 100-fpm Velocity and a Carbon Density of 30 lb/ft^3

of steam/min)/ft^2. These rates correspond to regeneration times of 30 to 90 min at steam regeneration ratios of 0.3 or 1 lb of steam/lb of carbon. Cooling and drying the beds can normally be done in 15 min. The minimum possible time for regeneration, drying, and cooling used in this study is 1 hr. Since the bed is loaded for the same period of time, the total minimum cycle for one bed takes 2 hr. Since two beds are usually employed, each carbon bed must have enough adsorption capacity to allow sufficient time for the other bed to be regenerated, dried, cooled, and placed back in adsorption service before breakthrough.

1. Bed Configuration---In the base case for carbon systems handling flows below 10,000 scfm two vertical tanks are used so that one bed can be regenerated while the other bed is adsorbing the VOC from the off-gas stream. For flows above 10,000 scfm vertical tanks would have diameters greater than 12 ft, which is above transportation limits; therefore horizontal tanks are required. For flows above 20,000 scfm three or more tanks are used in order to reduce capital cost by reducing the tank size and reducing carbon inventory. When three beds are used, one will be regenerating while the other two are adsorbing with parallel waste-gas flow. A sequence procedure must be established to prevent two tanks from being ready for regeneration at the same time.

3. Regeneration

a. Steam Requirements---Regeneration of a carbon bed saturated with VOC is most often accomplished by the use of steam. In regenerating a bed a certain amount of steam is required to heat the carbon bed from its operating temperature to the regeneration temperature and to provide the heat of desorption. However, most of the steam flow is needed to provide a sufficient concentration gradient to promote mass transfer of the adsorbate from the carbon bed. Even with extensive steam regeneration some VOC will be left on the bed. The adsorbate left on the carbon (the heel) after regeneration accounts for most of the difference between the saturated adsorption capacity and the operating capacity. For a given compound-carbon combination the amount of heel is determined by the amount of steam used during the regeneration cycle.

Figures II-4 and II-5 illustrate the effect of regeneration on the concentration of the adsorbate left on the carbon. Figure II-4 is the adsorption profile of a single compound just before a breakthrough occurs on the bed. This is the usual or desired status of the system just before regeneration. Figure II-5 shows the progression of the desorption profiles with increasingly larger amounts of steam passing through the bed. Profiles 1 and 2 are achieved with relatively small amounts of steam; profiles 3, 4, and 5 are the results of increasingly larger amounts of steam.[8]

Figure II-6 shows the effect that varying the steam regeneration ratio (lb of steam per lb of carbon) will have on the desorption efficiency. The S-shaped curve in Fig. II-6[13] indicates that a large amount of steam is required to achieve nearly 100% desorption efficiency (minimum heel) but that a relatively smaller amount is required to achieve 90% desorption efficiency (10% plus minimum heel left). If the designer is not limited by the effluent VOC concentration required, he has a choice of how much heel to leave on the bed. Based on Fig. II-6 an adsorption designer might choose between 0.25 and 0.35 lb of steam/lb of carbon as the preferred design condition, which will provide the greatest amount of operating capacity for the amount of steam used.

The desorption efficiency curve in Fig. II-6 is a function of the compound(s) adsorbed on the carbon, of the operating capacity of the adsorbent, and of the temperature and pressure of the regeneration steam. It may also be a weak function of steam regeneration rate [(lb of steam/min)/ft^2], but there are very little data in this area. A strongly adsorbed compound would have a curve skewed more to the right, since more steam would be required to remove it. A compound with a high loading capacity may require more steam per pound of carbon to account for the extra heat needed for the heats of desorption and the greater amount of material to be desorbed. Higher temperature regeneration steam may decrease the amount of steam required per pound of VOC removed (steam regeneration ratio) and may increase the amount of material desorbed. The net effect is that the curve will be skewed to the left and the heel remaining on the carbon will be less. The steam regeneration ratio may have an effect on the shape of the curve but will be most important when determining cycle times.

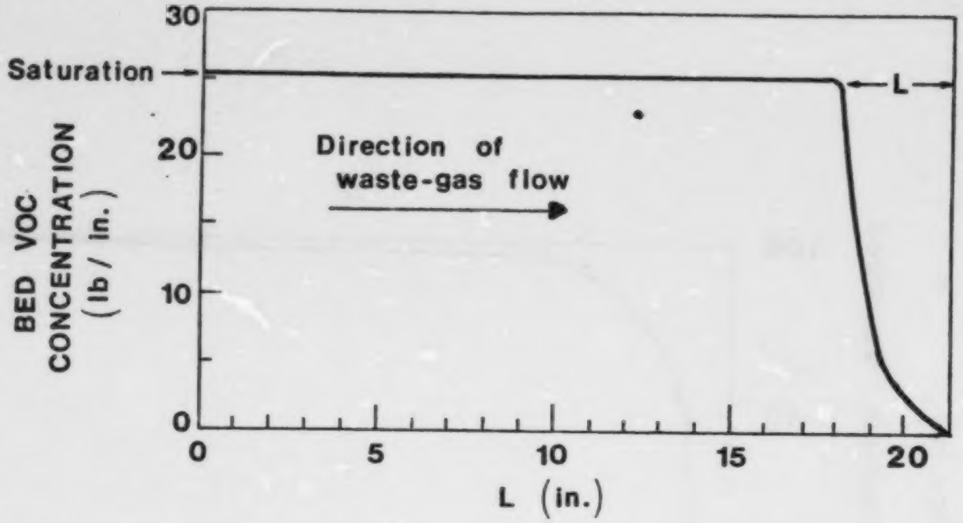


Fig. II-4. Adsorbed Phase Profile for Trichloroethylene at Service Time when Vapor Starts to Break Through the Bed; BPL V Type Carbon

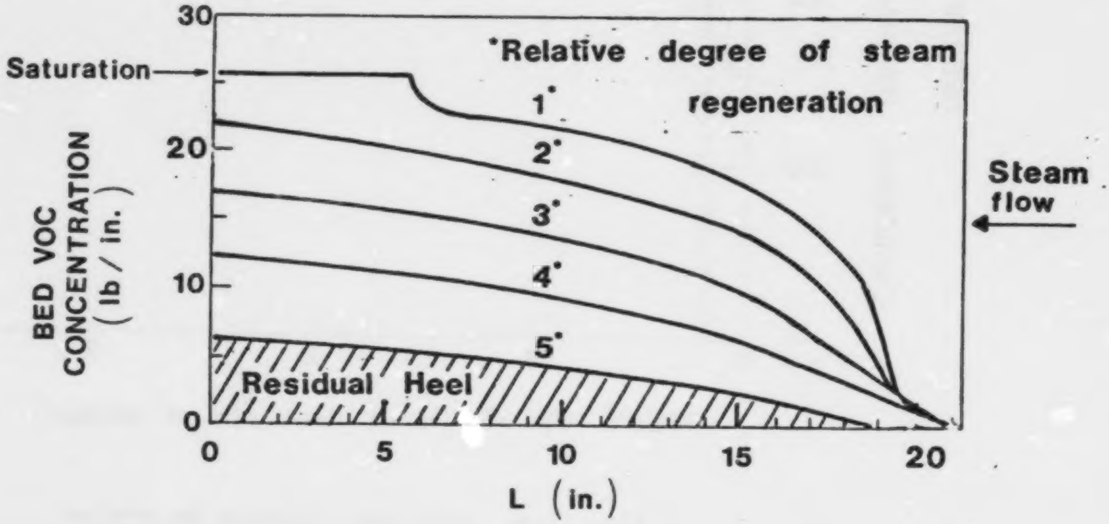


Fig. II-5. Adsorbed-Phase Profiles for Trichloroethylene at Various Stages of Regeneration; BPL V Type Carbon

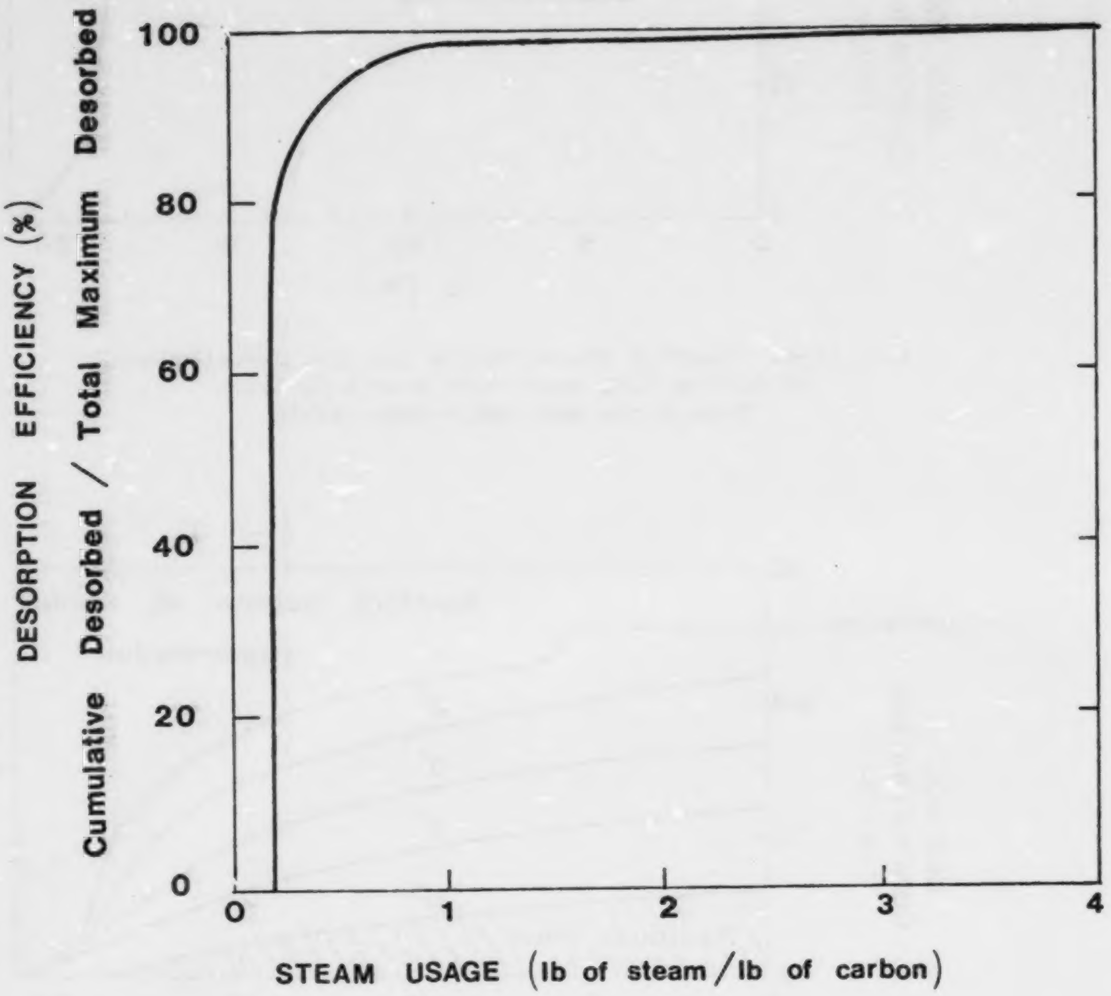


Fig. II-6. Methylene Chloride Desorption Efficiency Based on Steam Usage

Figure II-7 shows a generalized relationship between the amount of steam used for regeneration and the outlet VOC concentration during the next adsorption cycle. The exact relationship will depend on the type of VOC being removed and the operating characteristics of the system. In accordance with state-of-the-art carbon adsorption systems for solvent recovery, the outlet concentrations are usually in the range of 50 to 100 ppm_v.[6] This level may correspond to a steam regeneration ratio of 0.3 lb of steam/lb of carbon, the ratio normally required for solvent recovery adsorption systems. The lower achievable effluent concentration levels are in the range of 10 to 20 ppm_v,[14] which would correspond to a higher steam ratio. However, for some compounds effluent levels are achievable below 1 ppm_v. Figure II-7 shows that reduced effluent concentration is obtained by increasing the steam ratio and that very low effluent concentration levels may be obtained with high steam ratios. Figure II-7 is not meant to correspond to any one particular compound or adsorption condition but is used to illustrate a general trend. It shows that the position of the effluent concentration curve for each particular compound is a function of the adsorption temperature, regeneration temperature, and carbon operating capacity. The effluent concentration curve is relatively independent of inlet VOC concentrations. When the adsorption temperature increases, the effluent outlet concentration curve baseline may increase. Higher regeneration temperatures may shift the effluent outlet concentration curve downward. A different operating capacity may shift the curve laterally, since different amounts of steam may be required to regenerate the carbon. Data in this area are not readily available but could be generated in pilot-plant studies.

The achievable effluent quality values assumed for the purpose of evaluating adsorption systems in this study are the following: 0.3 lb of steam/lb of carbon will achieve an effluent quality of 70 ppm_v, and 1.0 lb of steam/lb of carobn will achieve an effluent quality of 12 ppm_v. Although these values may not be realized for all VOC compounds, they are appropriate for those compounds that are normally controlled by carbon adsorption.

b. Blower—For the base-case carbon adsorption system a blower is used following regeneration to provide drying and cooling air to sweep some VOC from the regenerated bed. To achieve the highest possible removal efficiency, regeneration should be started before an unacceptably effluent concentration occurs and

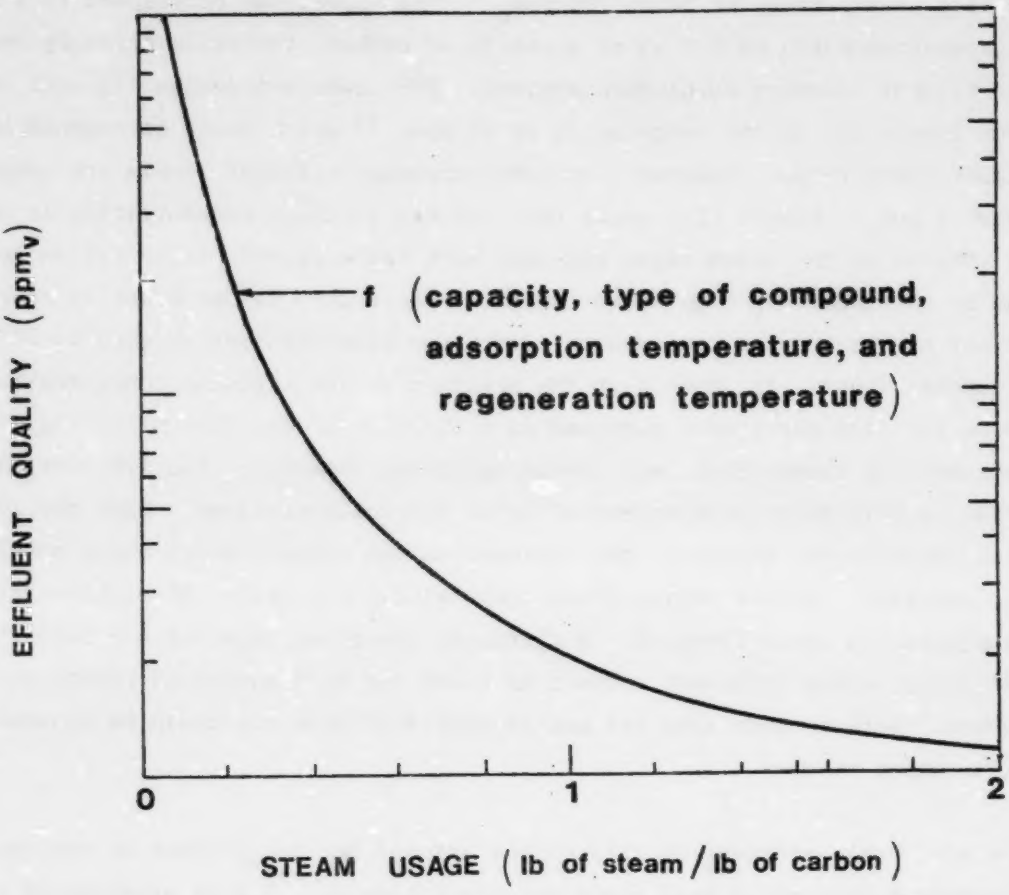


Fig. II-7. Effluent VOC Concentration Based on Steam Usage. (Not for Any Actual Compound)

the drying and cooling air should be sent to the adsorbing bed. Routing the drying and cooling air through the adsorbing bed requires a larger pressure drop for the drying and cooling air blower and main blower, additional valves and controls, and a slightly larger carbon bed. When additional air enters the adsorbing bed, no additional carbon capacity will be required since the concentration is low; however, a slightly larger cross-sectional area will be required because of the increased flow rate. This practice of routing the drying and cooling gas may not be practical for all cases since additional water will be brought into the adsorbing bed, which may affect the operating capacity of the carbon and cause operational problems.

The flow rate of the drying and cooling air blower is assumed to be about 30% of the off-gas flow rate. The pressure drop for the blower will be the total of the pressure drop for the regeneration bed and adsorbing bed, since the air is routed through both beds. For pressure-drop calculations it is assumed that 4 X 10 mesh carbon is used, that the bed depth is 3 ft, and that the superficial gas velicty is 100 fpm for the total cooling air and gas flow. The drying and cooling time is 15 min per cycle.

c. Condenser—All the steam required to regenerate the carbon has to be condensed and cooled to 100°F. Some of the heat will stay with the bed and be removed by the drying and cooling air, but most of it has to be removed by the condenser. The reduction in heat duty for the condenser is not significant; so the heat duty for the condenser is based on the amount of steam required to regenerate the bed. For the base-case design it is assumed that the steam will be used during 75% of the regeneration time; therefore the condenser will have to be sized to handle instantaneous heat duty, which is 33% more than the average steam consumption.

For the base-case design, atmospheric steam at 212°F and 970 Btu/lb of heat of vaporization was used. The condenser was designed to condensate the steam and VOC, cool the condensate mixture to 100°F, and raise the cooling water from 85°F to 120°F.

The overall heat transfer coefficient for the condenser was assumed to be 150 Btu/(hr)(ft^2)(°F) (ref 15). The area of the condenser per pound of carbon as shown in Fig. II-8 was based on various steam requirements and on a log-mean (or conservative) Δt of 42.4°F.

Although a decanter to separate the organic from the water is included in the battery limits of the carbon adsorption system, no additional equipment is included to separate water-soluble organics. Some separation option must be considered when large quantities of organics enter the condensate since most local authorities will not allow such water to be discharged into municipal sewage treatment systems. A complex distillation system may be required to fractionate the mixture into separate components, or a simple system can be designed to merely strip out the organics.

Other options for separation of the water-soluble compounds from the condensate include liquid extraction or liquid-phase carbon adsorption with solvent regeneration.

d. Alternatives to Steam Regeneration——Hot inert-gas regeneration and vacuum regeneration can be used as alternatives to steam regeneration. With the first method, after hot gas is used to regenerate the carbon bed, the VOC-laden gas can be incinerated. Another method is to recirculate the inert gas through a preheater, into the adsorber, and through a condenser. Each pass through the bed with the hot inert gas will pick up additional VOC of higher molecular weights. Removal from the adsorber and condensation of the VOC will continue until an equilibrium is reached between the bed, the hot inert gas, and the condenser. Higher gas temperatures or lower condenser temperatures will improve the recovery efficiency of the system.

In the second method, which involves indirect heating and a vacuum applied to the carbon bed, the boiling points of the VOC will be lowered and the VOC will be more easily removed from the bed. The vacuum regeneration cycle begins with the bed being heated with recirculating heated air or inert gas. Auxiliary heating coils within the bed are sometimes used. When the bed reaches the specified temperature, a vacuum pump then reduces the pressure in the bed to about 0.2 in. H_2O. The high boilers thereby removed are condensed with a chilled-water condenser, and the low-boiling VOC are condensed with a Freon-cooled condenser (-40°C). After the desorption step is complete, the bed is

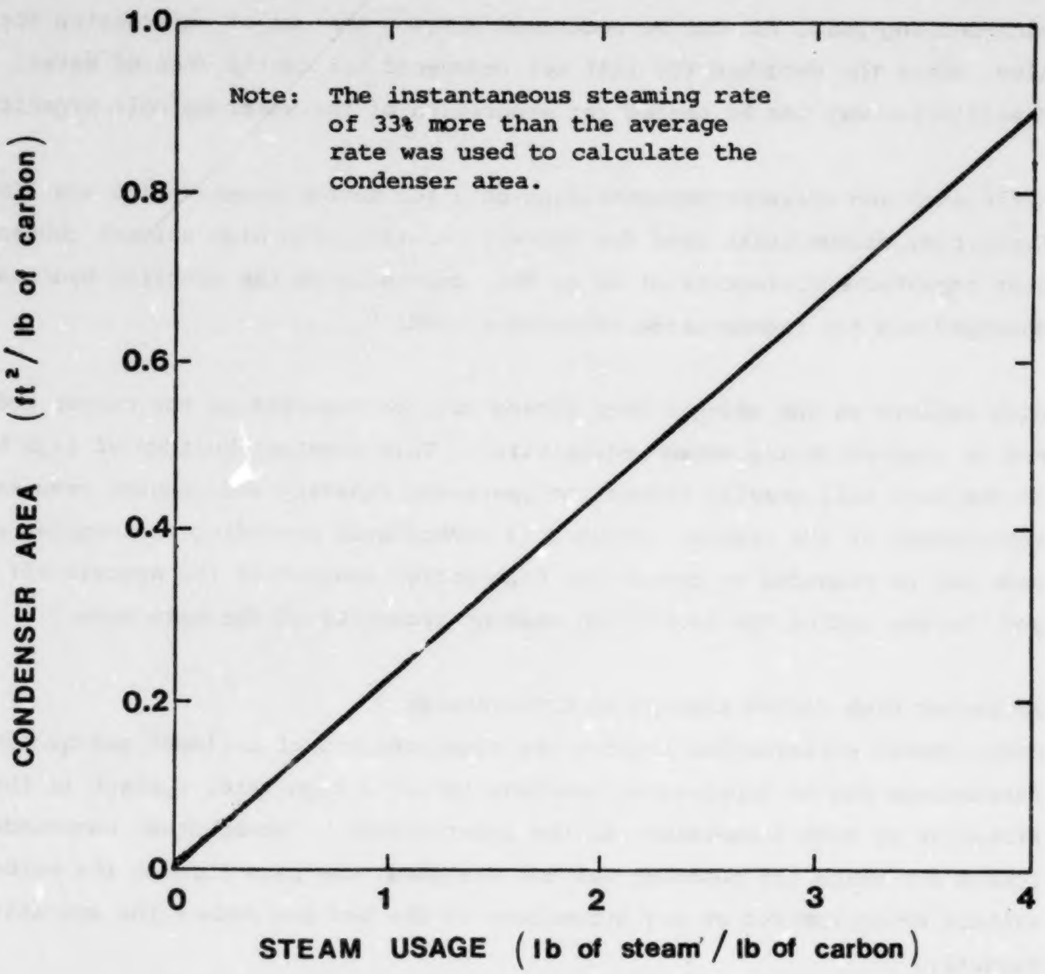


Fig. II-8. Condenser Area Based on Steam Usage

restored to atmospheric pressure and is cooled by recirculating air. A flow diagram of a vacuum regeneration system is shown in Fig. II-9.

The advantages of vacuum regeneration with indirect heating are that some high-boiling-point VOC can be recovered without the use of superheated steam. Also, since the desorbed VOC that are recovered are mostly free of water, distillation may not be needed for separation of the water-soluble organics.

Efficiency and effluent concentration data for vacuum regeneration are limited. Commercial vacuum units used for solvent recovery with high solvent concentration have reported efficiencies of 90 to 99%, depending on the specific hydrocarbon adsorbed and the regeneration conditions used.[16]

High boilers in the off-gas feed stream will be adsorbed on the carbon and will not be removed during steam regeneration. This constant buildup of high boilers in the heel will greatly reduce the operating capacity and require frequent replacement of the carbon. Disposable carbon beds preceding the regular carbon beds may be required to reduce the high-boiler content of the process off-gas and thereby reduce the carbon replacement frequency of the main beds.

4. Achieving High Carbon Adsorption Efficiencies

High removal efficiencies require the close control of influent gas quality. Performance can be impaired by particulates or a high water content in the inlet stream or by high temperature in the inlet stream. "Unexpected" compounds (those for which the adsorber was not designed) may pass through the carbon bed without being removed or may accumulate in the bed and reduce the operating capacity.

Prevention of premature breakthrough (unacceptable effluent concentration) requires a favorable balance between the adsorption capacity dictated by the mass flow rate of VOC and the speed and effectiveness with which the adsorber can be desorbed, cooled, and dried.

To avert the discharge of VOC from a hot, wet adsorber, piping must be arranged so that the adsorber can be dried and cooled and the drying cooling gas recycled to an on-line adsorber. There must be sufficient time in the total adsorption cycle for the bed to be dried and cooled.

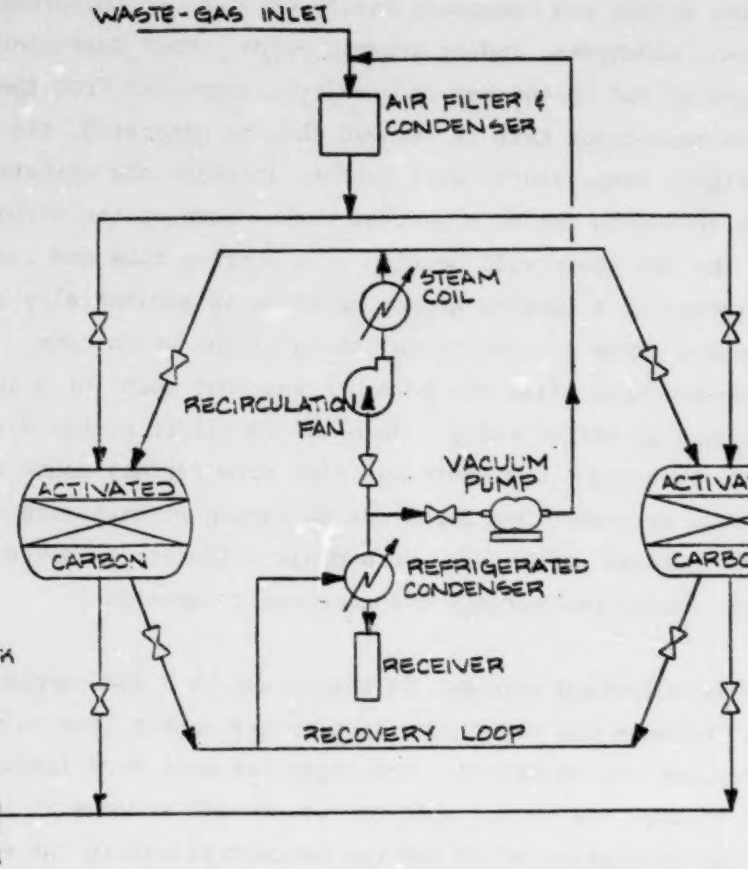

WASTE-GAS INLET
AIR FILTER & CONDENSER
STEAM COIL
RECIRCULATION FAN
VACUUM PUMP
ACTIVATED CARBON
ACTIVATED CARBON
REFRIGERATED CONDENSER
RECEIVER
STACK
RECOVERY LOOP
FAN

Fig. II-9. Vacuum Regeneration System

5. Safety Considerations

Spontaneous combustion of fixed beds of carbon can occur whenever the gas stream contains oxygen and compounds easily oxidized in the presence of carbon, such as ketones, aldehydes, and/or organic acids. Heat generated by adsorption or by oxidation of VOC in the bed is usually transported from the bed by convection. If less convection heat is removed than is generated, the bed temperature will rise. Higher temperatures will further increase the oxidation decomposition, and hot spots exceeding the autoignition temperature of the carbon may develop in the bed. The hot spots will develop in a shorter time and the condition will be aggravated if a limited amount of steam is accidentally admitted to the bed from a leak or from a valve being opened at the wrong time. A number of bed fires have occurred after the adsorber was shut down for a long period and then not regenerated sufficiently. When the VOC-laden stream was reintroduced, bed combustion occurred. Hot spots may also form rapidly under abnormal bed conditions, such as uneven bed depth due to carbon movement and stagnant bed areas.[14] When ketones, aldehydes, or organic acids are involved in the operation of a bed, safety precautions are especially important.

When the bed is adsorbing ketones, it should not be dried completely after regeneration, because the water present provides a heat sink to dissipate the heat of adsorption and oxidation. Bed fires are much more likely when the bed is permitted to dry. To ensure safe operation with ketones it is necessary to have an on-line monitoring of CO and CO_2 concentrations in the effluent stream. At shutdown the bed should be regenerated and cooled before it is left idle. The valves should be routinely inspected to ensure against steam leaks. Also, the exclusion of oxygen from the bed will help to control hot spots. This discussion does not imply that safe operation is impossible; on the contrary, there are several examples of ketones having been successfully recovered via carbon adsorption. It does mean, however, that there are potential hazards that should be considered.[14]

B. ALTERNATIVE CARBON ADSORPTION SYSTEMS

1. Fluidized-Bed Carbon Adsorption

Currently a fluidized-bed carbon adsorption process is commerically available from Union Carbide Corporation, who licensed the process from a Japanese company.

The carbon particles are designed to have a high attrition resistance so that they can withstand the abrasive action in the fluidized bed. The carbon particles are manufactured from shaped molten petroleum pitch. Being thermoplastic in nature, the material is formed into microspherical particles by its own surface tension. The particles are then carbonized and activated by steam. Because they are formed from molten material, they are almost spherical and their structure is homogeneous and strong.[17]

Figure II-10 is a basic flow sheet for the fluidized-bed carbon adsorption system. The system consists of a multistage countercurrent fluidized-bed adsorption section, a pressure-sealing section, a moving-bed desorption system, and another sealing section with carbon recycle. The regenerated carbon is swept by carrier gas from the bottom to the top of the column. In the adsorption section the carbon is fluidized and moves across perforated plates and down the column by a system of overflow weirs. The adsorption section design allows the carbon to contact the gas homogeneously, resulting in high mass-transfer efficiency. The pressure drop per stage normally ranges from 0.4 to 0.9 in. H_2O, with six to eight stages required, depending on the application. The gas velocity through the adsorption section is as high as 200 fpm, which is 2 to 4 times that required for fixed beds. This high gas velocity allows the cross-sectional area of the bed to be smaller, with the pressure drop across the entire bed being 2.4 to 7.2 in. H_2O.[17]

The regeneration section is a dense-phase gravity-flow bed with indirect heating. The VOC are removed from the bed by an inert-gas regeneration fluid being passed through the bed or by only direct steaming of the bed. The desorption temperature is normally around 250°F but can be raised to 500°F to remove high-boiling-point materials. By using a continuous system of regeneration no heat is lost due to the bed being cycled; so the heating requirements are reported to be less than those for fixed-bed adsorption systems.[15]

For the solvent recovery systems in commercial operation the treated gas effluent concentration is typically around 50 ppm of VOC. Effluent concentration data show that outlet levels of 10 ppm have been achieved for some applications.[15]

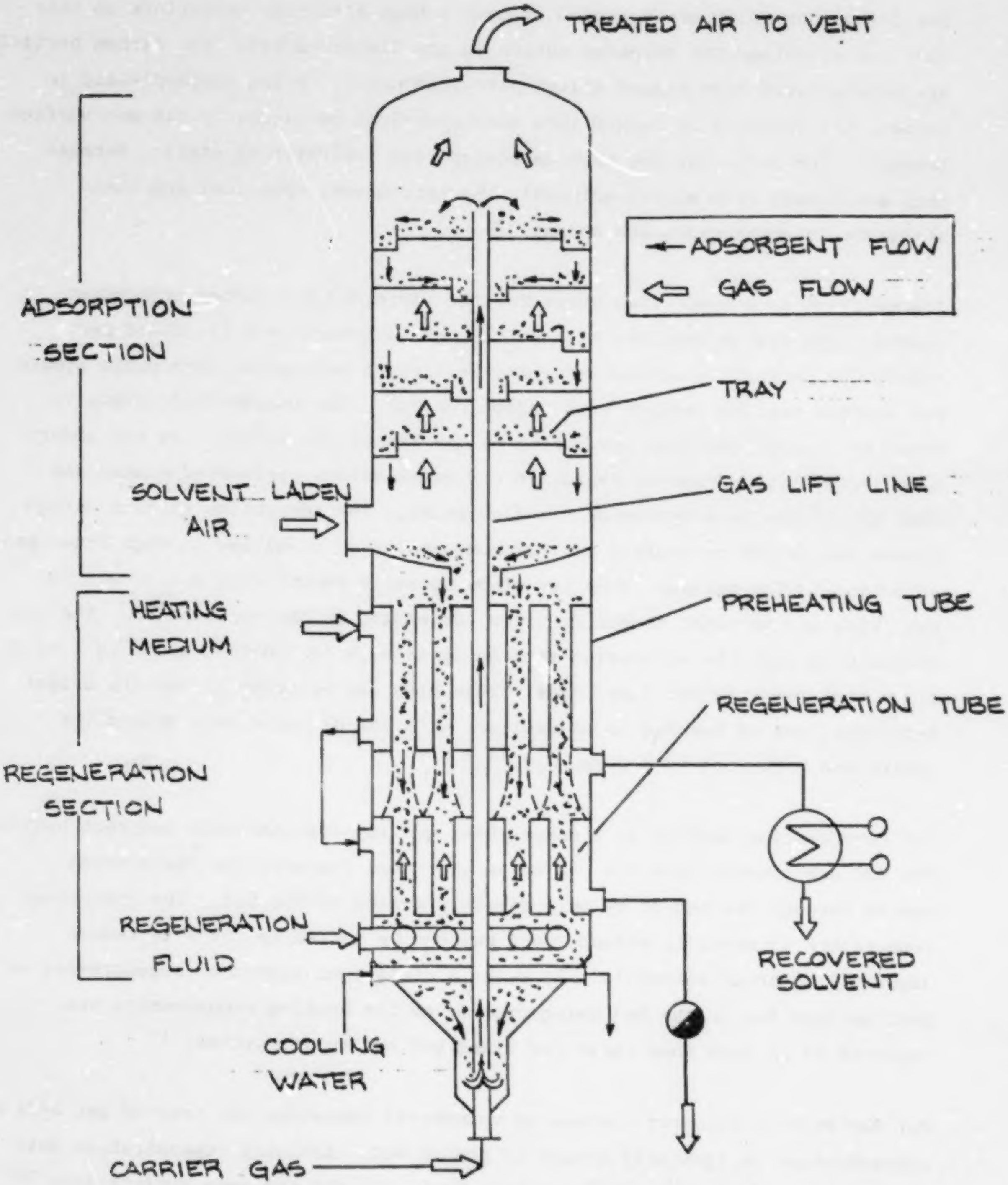

TREATED AIR TO VENT
ADSORBENT FLOW
GAS FLOW
ADSORPTION SECTION
TRAY
SOLVENT LADEN AIR
GAS LIFT LINE
HEATING MEDIUM
PREHEATING TUBE
REGENERATION TUBE
REGENERATION SECTION
REGENERATION FLUID
RECOVERED SOLVENT
COOLING WATER
CARRIER GAS

Fig. II-10. Fluidized-Bed Carbon Adsorption System

2. Activated-Carbon Fiber Systems

Currently a fixed-bed carbon adsorption system that uses a fibrous activated carbon instead of granular activated carbon is commerically available. Toyobo New York, Inc., is involved in marketing the carbon adsorption equipment in the United States. Their technology was developed and is currently being used in Japan. The fibrous carbon can be supplied in various forms, such as mats, corrugated paper, or honeycombs. The advantages of the fibrous carbon, as stated by Toyobo, over granular activated carbon are a greater apparent surface area, shorter adsorption paths, greater adsorption capacity, and lower pressure drops. The reason given for these advantages is that the fibrous carbon has a more uniform pore distributed with an average diameter in the range of 20 Å . The fibrous carbon can be used for such applications as recovery of solvents, pollution control, and gas masks.

3. Rotary Carbon Adsorption Systems

Cargo Caire Engineering Corporation is currently developing a rotary carbon adsorption system, which is designed to function as a concentrator of low-concentration high-flow VOC emissions. The system operates by passing a high volume of low-concentration VOC stream through the carbon rotors. The carbon rotor slowly turns into a regeneration section, where hot gas is passed through the carbon rotor to desorb the organic. This lower volume regeneration gas then can be sent to a smaller volume incinerator or fixed-bed adsorber.

III. CONSIDERATIONS FOR INSTALLING CARBON ADSORPTION EQUIPMENT

A. NEW PLANTS

Carbon adsorption systems are not normally placed in a building for protection from the elements of weather but are usually placed outside, near the process vents. The units are usually put on foundations on the ground, but can be elevated to accommodate other processing requirements. There should be enough room around the units to allow for the replacement of the carbon when necessary.

Utilities must be supplied to the carbon adsorption site. Electricity is needed for the blower motors, timers, relays, and recording equipment. Steam is required at a specified pressure and flow rate. The steam requirements are not continuous since steam is used for only part of the regeneration period. The steam should not contain any material that will affect the adsorption quality of the carbon or affect the recoverability of the organic. Cooling water is required for condensing and cooling of steam and organic. The temperature of the water must be low enough for the organic to be condensed, which may require the use of two condensers. The valves for the carbon adsorption unit are often automatic and require instrument air. Since adsorption units are usually located outside, the instrument air must be dry to prevent condensation and freezing of water. After the condensed steam has been separated form the organics, it may have to go to a wastewater treatment facility. The waste load on the wastewater treatment facility will depend on the steam flow rate and the amount of organics carried along with the condensed steam.

Carbon adsorption units are normally located in an area where solvent is used and follow the building safety codes required for solvent use applications; no additional safety precautions are normally necessary.

B. EXISTING PLANTS

All considerations for a new plant discussed here also apply to retrofitting carbon adsorption units in an existing plant. However, installation costs may be substantially higher since utility distribution systems and load capacities may not be adequate to accommodate the adsorption unit. If an additional steam boiler is required, it may be better to use hot inert-gas regeneration or vacuum regeneration. The cost and cost-effectiveness data presented in this report are not intended to apply to retrofitted carbon adsorption systems. In retrofitted systems additional costs may be encountered because of such items as demolition requirements, crowded construction working conditions, construction activities scheduled with production activities, and longer interconnecting piping. These factors are site-specific and no attempt has been made to provide costs. For specific retrofit cases rough costs may be obtained by using the new-site data and adding as required for a specific retrofit situation.

IV. COST AND ENERGY IMPACTS OF CARBON ADSORPTION

A. BASE-CASE ADSORBER DESIGN SUMMARY

Results are given here of the cost and energy-effectiveness calculations for the typical or base-case carbon adsorption systems discussed in the previous section. Operating costs have been calculated for the combinations of variables listed below and are itemized in the computer printouts attached to Appendix A. The variables are based on standard conditions at 32°F.

Steam costs (per million Btu): $2.50, $5.00, $10.00; carbon requirement (lb of carbon/1000 scf): 0.10, 0.50, 1.00, 1.39, 2.00, 5.00, 6.96, 8.00, 10.00; steam regeneration ratio (lb of steam/lb of carbon): 0.3, 0.6, 1.0, 2.0; credit: Five different recovery credits are costed. The amount of credit depends on the pound of VOC recovered from each 1000 scf of off-gas and the dollar value assigned to each pound and is expressed as $/1000 scf. The pounds of VOC recovered are approximately equal to the VOC content into the adsorber less the VOC content out of the adsorber (if the recovered VOC is insoluble in water). The conversion from ppm_v to VOC content can be done conveniently with the use of Fig. II-1. The method of calculating the credit value is shown in the annual cost sample calculation in Appendix A. Off-gas flow (scfm): 300, 1,000, 5,000, 20,000, 50,000, 100,000. The fixed factors are as follows: temperature, 100°F; gas velocity (superficial), 100 fpm; bed depth, 3 ft; pressure drop, 6.5 in. H_2O/ft; carbon, 4 X 16 mesh BPL carbon, 30 lb/ft^3; bed configuration, see Sect. II.A.2.1; all capital and operating costs other than steam cost.

B. COST BASIS

The estimated capital costs for the carbon adsorption systems presented in this section represent the total investment required for purchase and installation of all equipment and material to provide a facility as described in Sect. II. Included are all indirect costs such as engineering and contractors' fees and overheads. These are battery-limits costs and do not include provision for bringing utilities, services, or roads to the site, backup facilities, land, research and development required, or process piping and instrumentation interconnections that may be required within the process generating the waste-gas feed to the carbon adsorption system.

The method used to develop these estimated capital costs was based on applying factors to the purchase prices of equipment to arrive at an installed capital cost. The major portion of equipment and material costs was obtained from Richardson Rapid Construction Cost Estimating System, 1978—1980 edition. Ductwork purchase costs were obtained from Capital and Operating Costs of Selected Air Pollution Control Systems by M. L. Kinkley and R. B. Neveril of Gard, Inc. (EPA Report No. 450/3-76-014). Table IV-1 gives the factor ranges used for factoring up the purchased price of equipment to the installed cost and is based on historical data of IT Enviroscience. The expected accuracy of the total installed cost with this degree of engineering detail using this factor method is in the range of ±30%. This method of obtaining total installed capital costs is suitable for study or screening estimates.

For carbon adsorption systems a 20% allowance was added to the major equipment purchase cost to compensate for unspecified items. Adding 20% allowance to the estimated major equipment cost yielded the estimated equipment purchase cost (A). This established the basis for the application of all installed capital cost factors shown in Table IV-1.

The installation costs accounting for foundations, structures, equipment erection, piping, insulation, paint, fire protection, and instruments were made approximately 2.1 to 2.3 times the total equipment purchase cost to arrive at the base cost (B). Additional percentages were then applied to the base case as shown in Table IV-1 (sales tax, freight, contractor's fees, engineering, contingencies) to arrive at a total installed cost. The initial carbon charge based on $1.00/lb was added to this total to give a total battery-limit installed cost. The overall ratio of total installed cost to major equipment purchase (excluding the 20% allowance for unspecified items) is 3.8 for vertical package units and 4.3 for the larger horizontal systems.

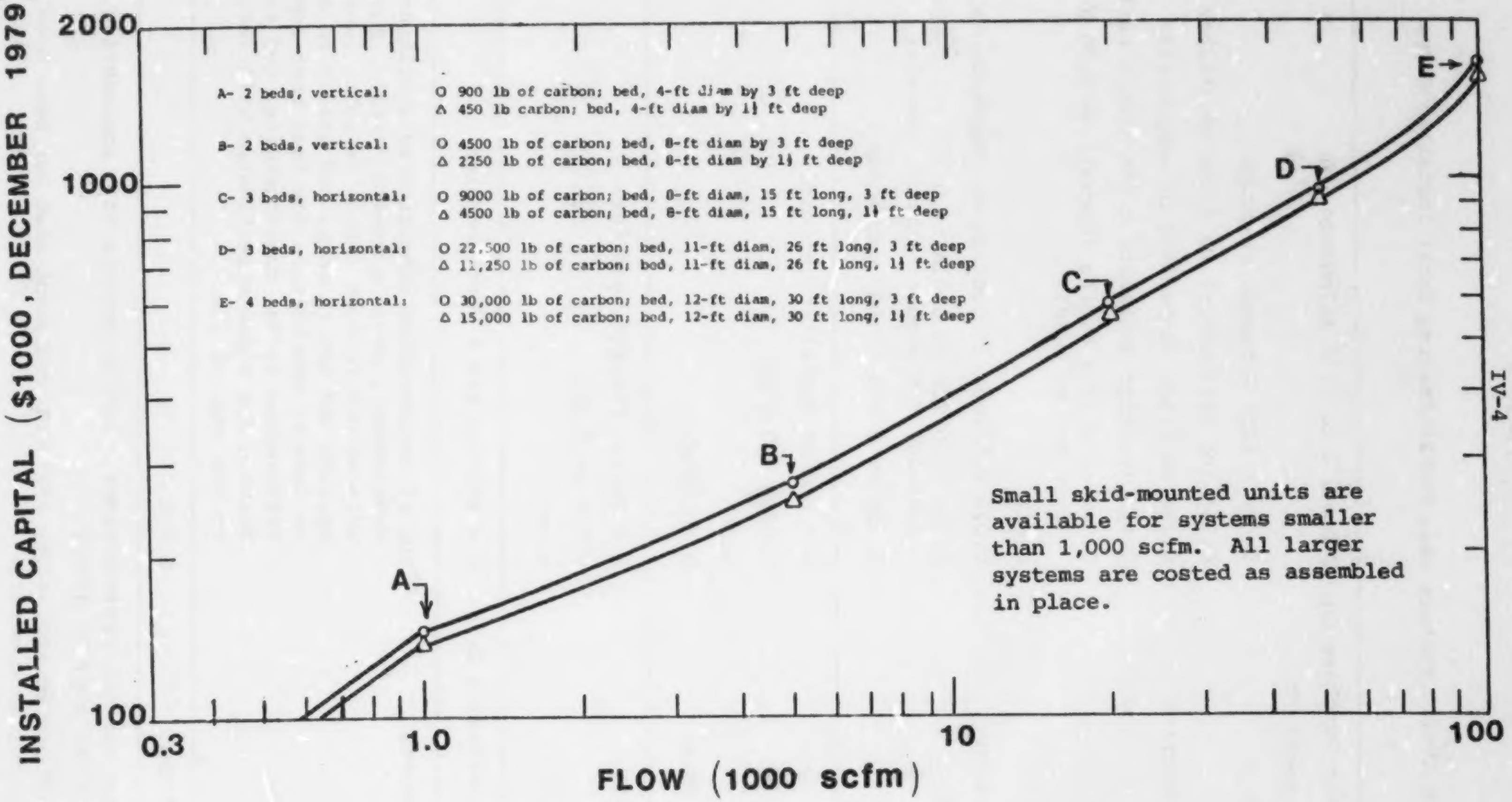
Capital costs of carbon adsorption systems are shown in Fig. IV-1. The curves represent the total estimated capital cost based on a carbon adsorption system with a superficial velocity of 100 fpm and a pressure drop of 6.5 in. H_2O/ft of carbon bed at carbon bed depths of 1.5 and 3 ft. The basic pieces of equipment as shown in Fig. I-1 are carbon adsorption vessels, process-waste-gas and ambient-air blowers, condenser, and decanter. Also included are the purchase

Table IV-1. Factors Used for Estimating Total Installed Costs

A = Major Equipment Purchase Cost Plus 0.1 to 0.35 Allowance	
Installation Costs	
Foundations	0.06A + $100 X number of pumps
Structures	0.15A (no structures) to 0.30A (multideck structures)
Equipment Erection	0.15A to 0.30A (depending on complexity)
Piping	0.40A (package units) to 1.10A (rat's nest)
Insulation	0.06A or 0.15 X piping (normal) to 0.30 X piping (bulk hot or cold)
Paint	0.05A
Fire Protection	0.01A to 0.06A (depending on requirements)
Instruments	0.10A to 0.30A or 0.01A to 0.25A + $50,000 to $300,000 for process control computer
Electrical	0.15A or 0.05A + $500 per motor
B = Base Cost	A + Sum of Installation Costs
Sales Tax	0.025A + 0.025B
Freight	0.16A
Contractor's Fees	0.30 (B-A)
C = Total Contract	B + Taxes, Freight, and Fees
Engineering[a]	0.01C to 0.20C
Contingencies[b]	0.15C
D = Process Unit Installed Cost	C + Engineering + Contingencies
E = Total Subestimates	Sum of semidetailed subestimates (buildings, site development, cooling towers, etc.). Each subestimate should include taxes, freight, fees, engineering and contingency, and should be escalated to date of expenditure for that cost component. Engineering costs, contingencies, and escalation factors for these subestimates will vary according to the type of job.
F = Total Project Cost	D + E

[a] Includes cost from capital project teams, process engineering, engineering, purchasing, and other support groups.

[b] Contingency should not be applied to any cost component that has been committed by either purchase order or contract.



Small skid-mounted units are available for systems smaller than 1,000 scfm. All larger systems are costed as assembled in place.

Fig. IV-1. Installed Capital Cost of Carbon Adsorption Systems

costs of automatic butterfly valves, interconnecting ducts, and steam control valves and a minimum allowance for piping or ducts required to get the vapors and utilities to the system.

C. ANNUAL COSTS

Annual costs for various operating conditions are presented in Appendix A. These costs are the bases for the cost-effectiveness graphs included in the report. The parameters used in calculating these annual costs are defined in Table IV-2. The capital cost of the carbon adsorption system was based on a bed depth of 3 ft. Figures IV-2 through IV-5 represent the annual cost of using a carbon adsorption system for four different steam regeneration requirements. The cost estimating variance for systems smaller than 1000 scfm (noted on Fig. IV-1) causes a discontinuity at 1000 scfm for all curves shown on Figs. IV-2 through IV-5. Table IV-3 shows the effect on annual cost of varying the carbon life from 5 to 2 years and the cost of steam from $2.50/million Btu to $5.00/million Btu.

D. COST AND ENERGY EFFECTIVENESS

The cost effectiveness and energy effectiveness were calculated by dividing the annual cost for a particular option (Appendix A) or the fuel usage in Btu/yr by the total annual amount of VOC removed with adsorption removal efficiencies assumed as discussed in Sect. II.A.3. In this analysis the steam regeneration rate of 0.3 lb/lb of carbon will correspond to an effluent quality of 70 ppm_v. For steam regeneration rates of 1 lb of steam/lb of carbon the corresponding effluent quality will be 12 ppm_v. It is assumed that these effluent concentrations will not change for different feed concentrations.

The cost effectiveness is given in Table IV-4 and the energy effectiveness in Table IV-5. Figure IV-6 shows the relationship of flow rate vs cost effectiveness for two carbon requirements* at two steam regeneration requirements. Figures IV-7, 8, and 9 show the effect of increased steam regeneration rates at different carbon requirements and various flow rates.

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*For all cost-effectiveness calculations in this report a carbon operating capacity of 0.10 lb of VOC/lb of carbon is assumed. The carbon requirement of waste gas is therefore dependent entirely on the VOC concentration in the process waste gas.

Table IV-2. Annual Cost Parameters

Operating factor	8760 hr/yr
Fixed costs	
Maintenance labor plus materials, 6%	29% installed capital
Capital recovery, 18%*	
Taxes, insurances, administration charges, 5%	
Utilities	
Electric power	$0.03/kWh
Steam	$2,50, $5.00, and $10.00/million Btu
Cooling water	$0.10/1000 gal
Carbon adsorption cost (5-yr replacement)	$1.17/lb

*Based on 10-year life and 12% interest.

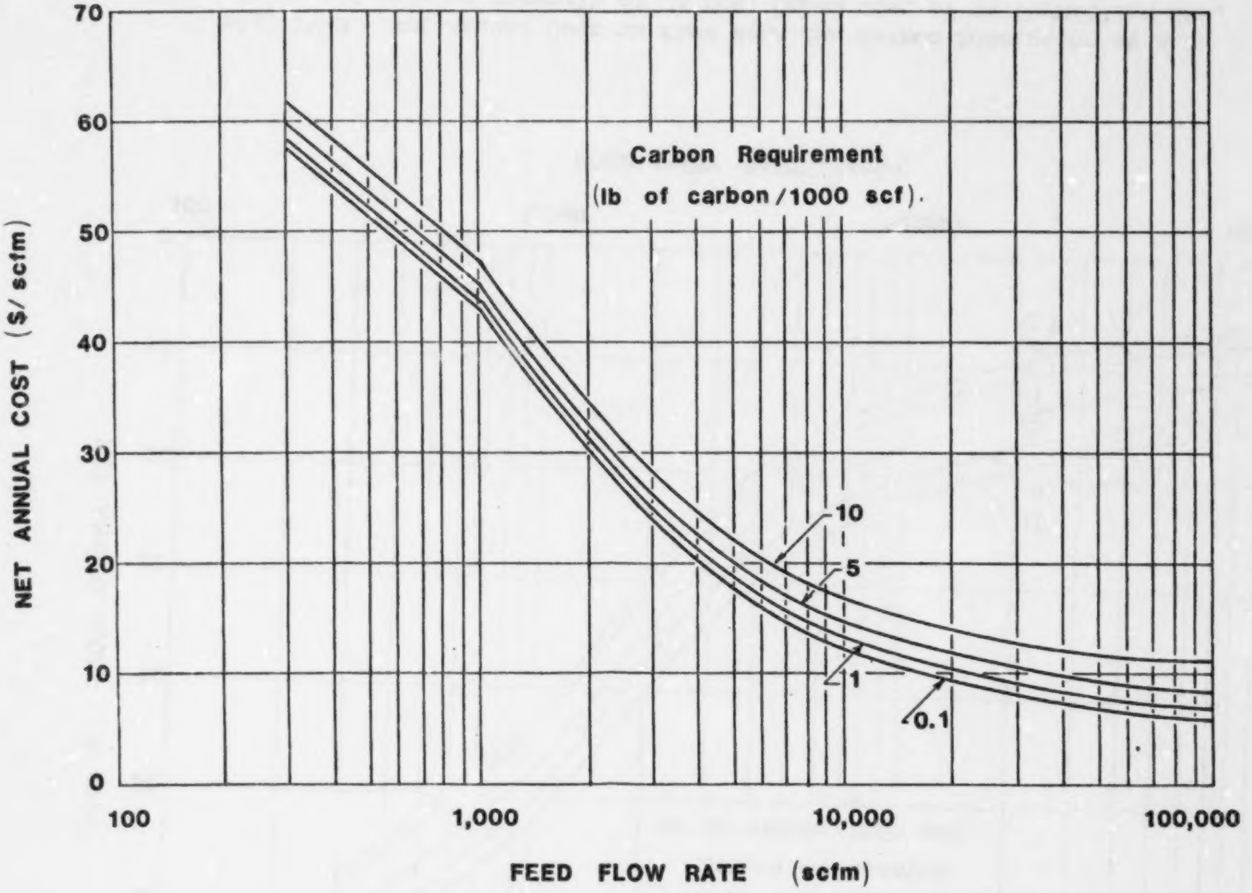


Fig. IV-2. Net Annual Cost vs Flow Rate for Carbon Adsorption at a Steam Rate of 0.3 lb of Steam/lb of Carbon, No Credit for Recovered VOC, and a Steam Cost of $2.50/Million Btu

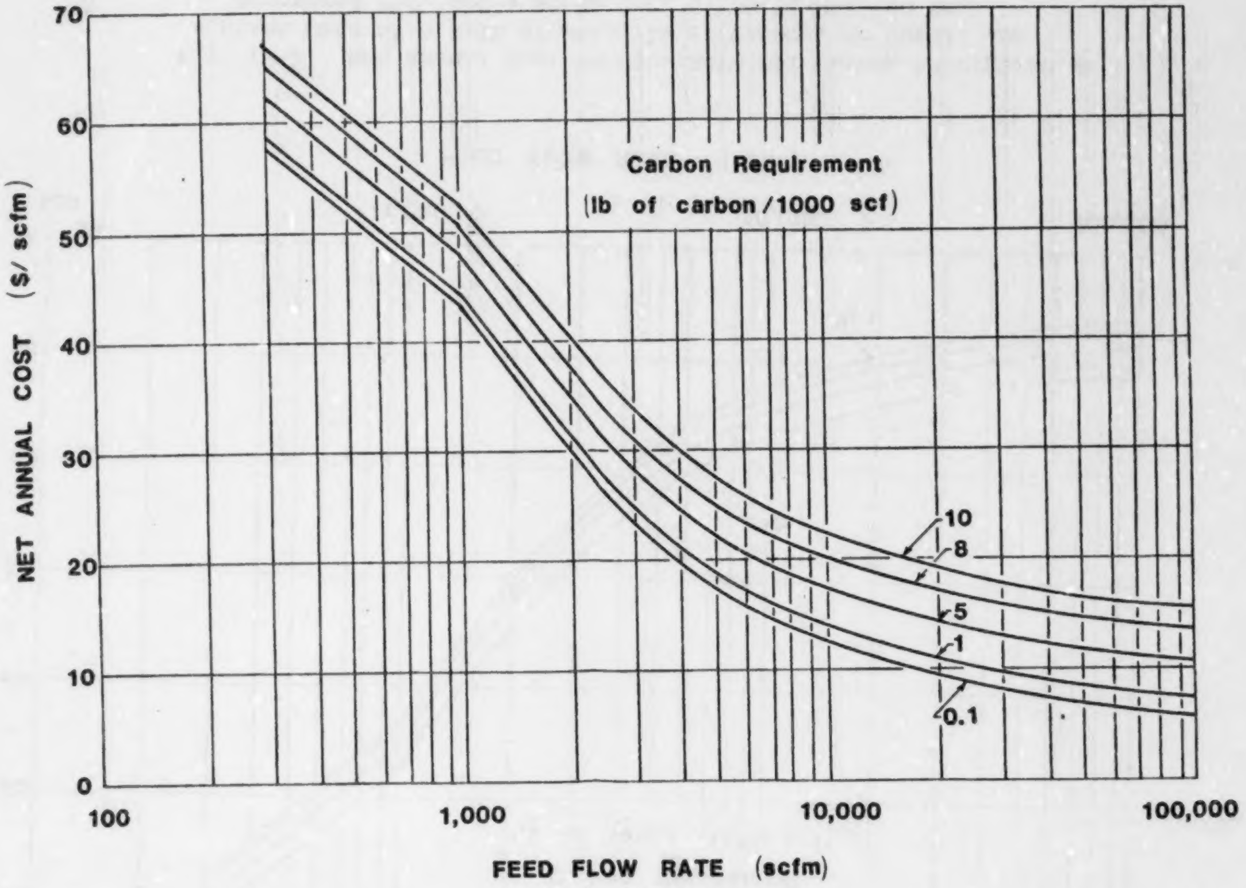


Fig. IV-3. Net Annual Cost vs Flow Rate for Carbon Adsorption at a Steam Rate of 0.6 lb of Steam/lb of Carbon, Steam Cost of $2.50/Million Btu, and No Credit for Recovered VOC

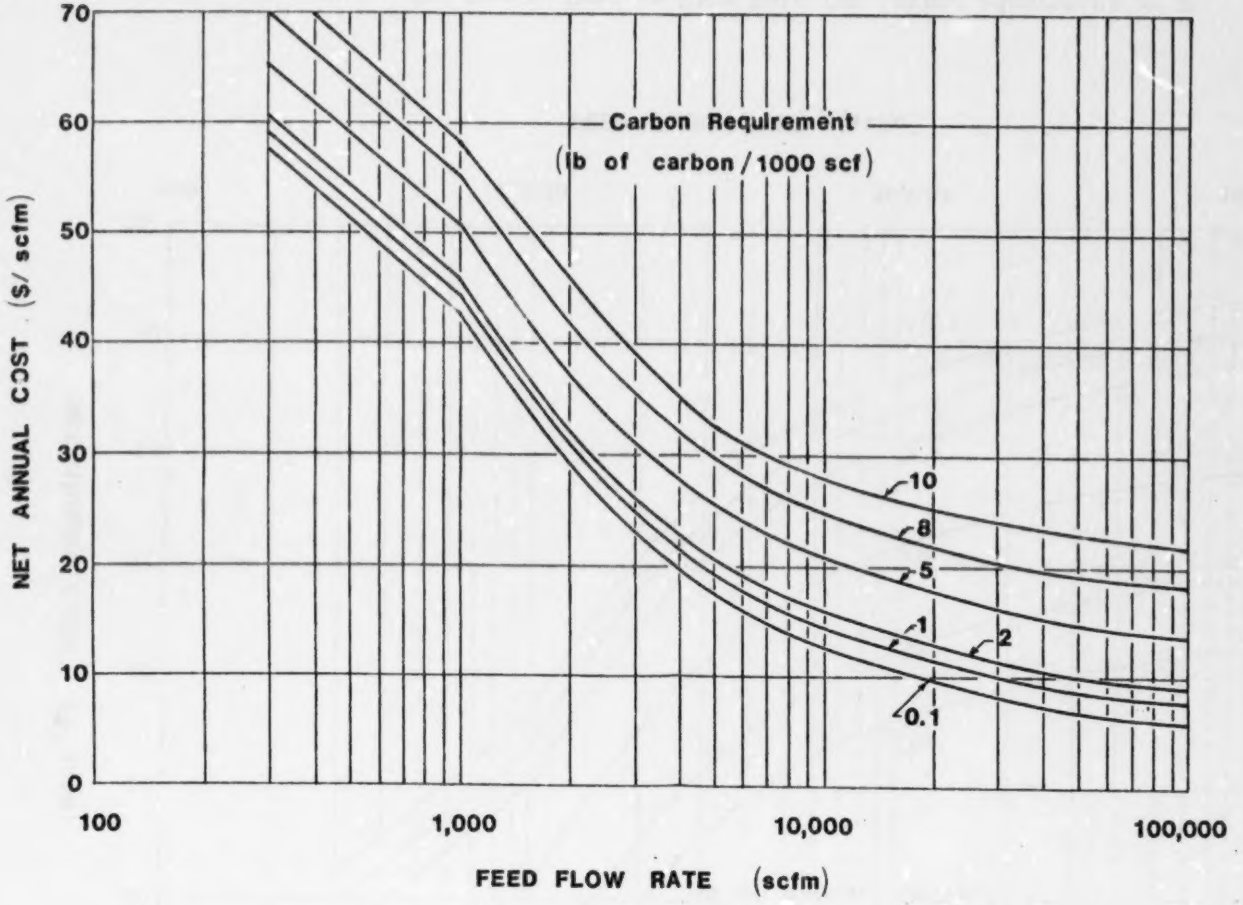


Fig. IV-4. Net Annual Cost vs Flow Rate for Carbon Adsorption at a Steam Rate of 1 lb of Steam/lb of Carbon, No Credit for Recovered VOC, and a Steam Cost of $2.50/Million Btu

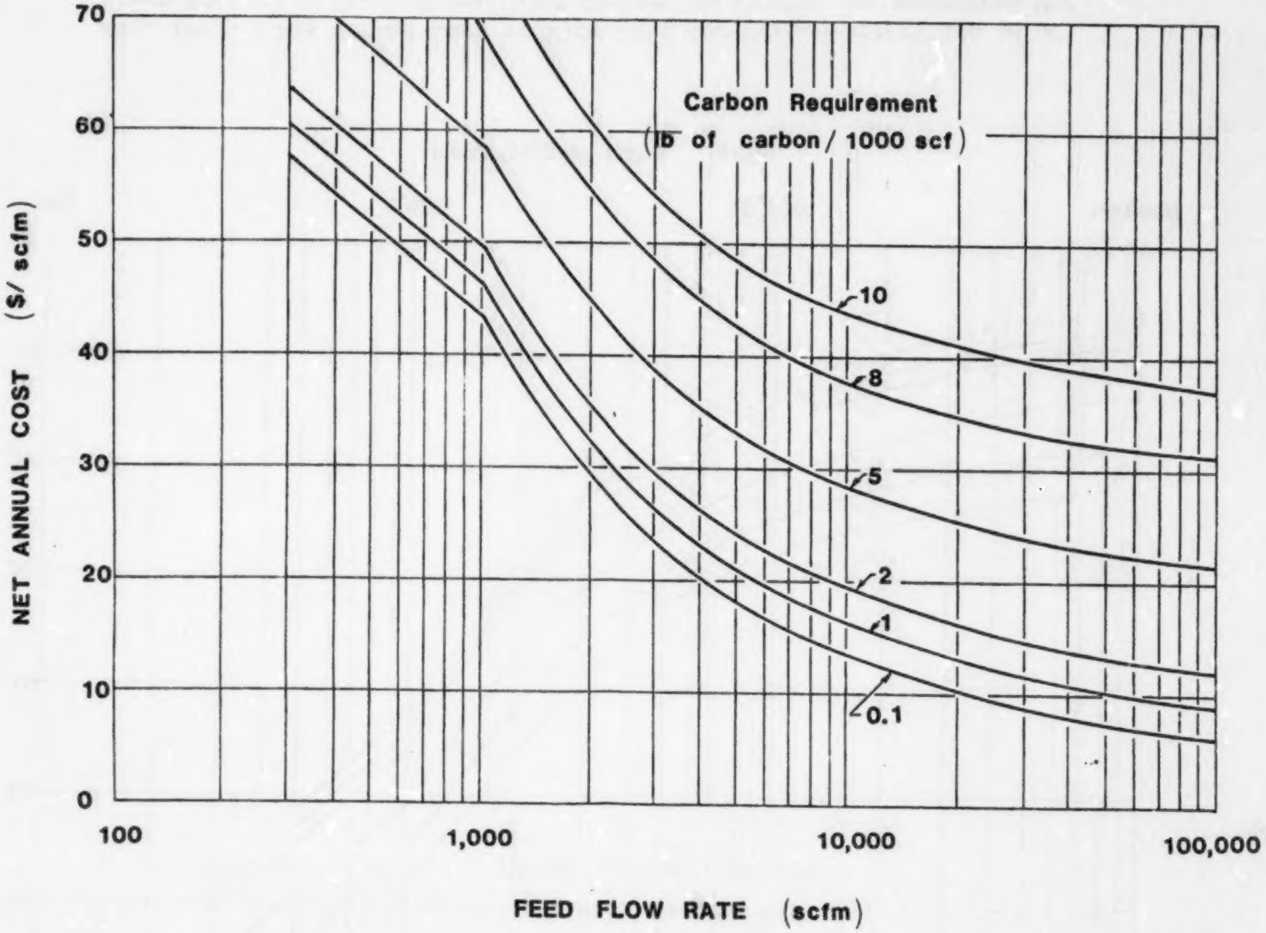


Fig. IV-5. Net Annual Cost vs Flow Rate for Carbon Adsorption at a Steam Rate of 2 lb of Steam/lb of Carbon, No Credit for Recovered VOC, and a Steam Cost of $2.50/Million Btu

Table IV-3. Cost Effect of Varying Carbon Life and Steam Price

Annual Cost[a]	Case I[b]	Case II[c]	Case III[d]
Fixed	$81,276	$81,276	$84,435
Utilities	7,167	9,076	7,167
Total	$88,443	$90,352	$91,602

[a] Sample calculations based on carbon requirement of 1.0 lb of carbon/1000 scf, a steam regeneration rate of 0.3 lb of steam/lb of carbon, and a flow rate of 5000 scfm.

[b] Steam cost, $2.50/million Btu; carbon life, 5 years.

[c] Steam cost, $5.00/million Btu; carbon life, 5 years.

[d] Steam cost, $2.50/million Btu; carbon life 2 years.

Table IV-4. Cost Effectiveness of Carbon Adsorption for Removal of VOC
(Steam Cost, $2.50/Million Btu)

				Cost Effectiveness (per lb of VOC removed)					
				70-ppm$_v$ Effluent[b]			12-ppm$_v$ Effluent[c]		
Carbon Requirement (lb of carbon/1000 scf)	Flow Rate (scfm)	VOC Removal (lb/hr)[a,b]	VOC Removal (lb/hr)[a,c]	No VOC Credit	$0.05/lb of VOC Credit	$0.10/lb of VOC Credit	No VOC Credit	$0.05/lb of VOC Credit	$0.10/lb of VOC Credit
0.5 (~359 ppm$_v$)[a]	300	0.72	0.87	$2.74	$2.69	$2.64	$2.29	$2.24	$2.19
	1,000	2.41	2.90	2.04	1.99	1.94	1.73	1.68	1.63
	5,000	12.07	14.50	0.83	0.77	0.72	0.71	0.66	0.61
	20,000	48.30	58.00	0.48	0.43	0.38	0.43	0.37	0.32
	50,000	120.75	144.99	0.33	0.27	0.22	0.30	0.25	0.20
	100,000	241.50	289.97	0.30	0.25	0.20	0.27	0.22	0.17
1.393 (~1000 ppm$_v$)[a]	300	2.33	2.47	0.85	0.80	0.75	0.83	0.78	0.73
	1,000	7.77	8.25	0.64	0.59	0.54	0.63	0.58	0.53
	5,000	38.86	41.28	0.26	0.21	0.16	0.27	0.22	0.17
	20,000	155.43	165.13	0.16	0.11	0.05	0.17	0.12	0.07
	50,000	388.57	412.81	0.11	0.06	0.01	0.12	0.07	0.02
	100,000	777.16	825.62	0.10	0.05	+0.008	0.11	0.06	0.01
6.96 (~5000 ppm$_v$)[a]	300	12.36	12.50	0.17	0.12	0.07	0.19	0.14	0.09
	1,000	41.20	41.68	0.13	0.08	0.03	0.15	0.10	0.05
	5,000	206.00	208.41	0.06	0.006	+0.04	0.08	0.03	+0.02
	20,000	823.96	833.65	0.04	+0.01	+0.06	0.06	0.01	+0.04
	50,000	2059.89	2084.12	0.03	+0.02	+0.07	0.05	+0.001	+0.05
	100,000	4119.78	4168.24	0.03	+0.02	0.07	0.05	+0.004	+0.05

Table IV-4. (Continued)

				Cost Effectiveness (per lb of VOC removed)					
				70-ppm$_v$ Effluent[b]			12-ppm$_v$ Effluent[c]		
Carbon Requirement (lb of carbon/1000 scf)	Flow Rate (scfm)	VOC Removal (lb/hr)[a,b]	VOC Removal (lb/hr)[a,c]	No VOC Credit	$0.05/lb of VOC Credit	$0.10/lb of VOC Credit	No VOC Credit	$0.05/lb of VOC Credit	$0.10/lb of VOC Credit
10 (∿7180 ppm$_v$)[a]	300	17.82	17.97	$ 0.12	$ 0.07	$ 0.02	$ 0.14	$ 0.09	$ 0.04
	1,000	59.42	59.90	0.09	0.04	+0.01	0.11	0.06	0.01
	5,000	297.08	299.50	0.04	+0.008	+0.06	0.06	0.01	+0.04
	20,000	1188.3	1198.00	0.03	+0.02	+0.07	0.05	+0.001	+0.05
	50,000	2970.75	2994.99	0.02	+0.03	+0.08	0.04	+0.007	+0.06
	100,000	5941.50	5989.97	0.02	+0.03	+0.08	0.04	+0.009	+0.06

[a] Assumes a VOC molecular weight of 50 and carbon operating capacity of 0.10 lb of VOC/lb of carbon.

[b] Assumes that a baseline effluent of 70 ppm$_v$ can be achieved with 0.3 lb of steam/lb of carbon.

[c] Assumes that a baseline effluent of 12 ppm$_v$ can be achieved with 1 lb of steam/lb of carbon.

Table IV-5. Energy Effectiveness of Carbon Adsorption for VOC Removal

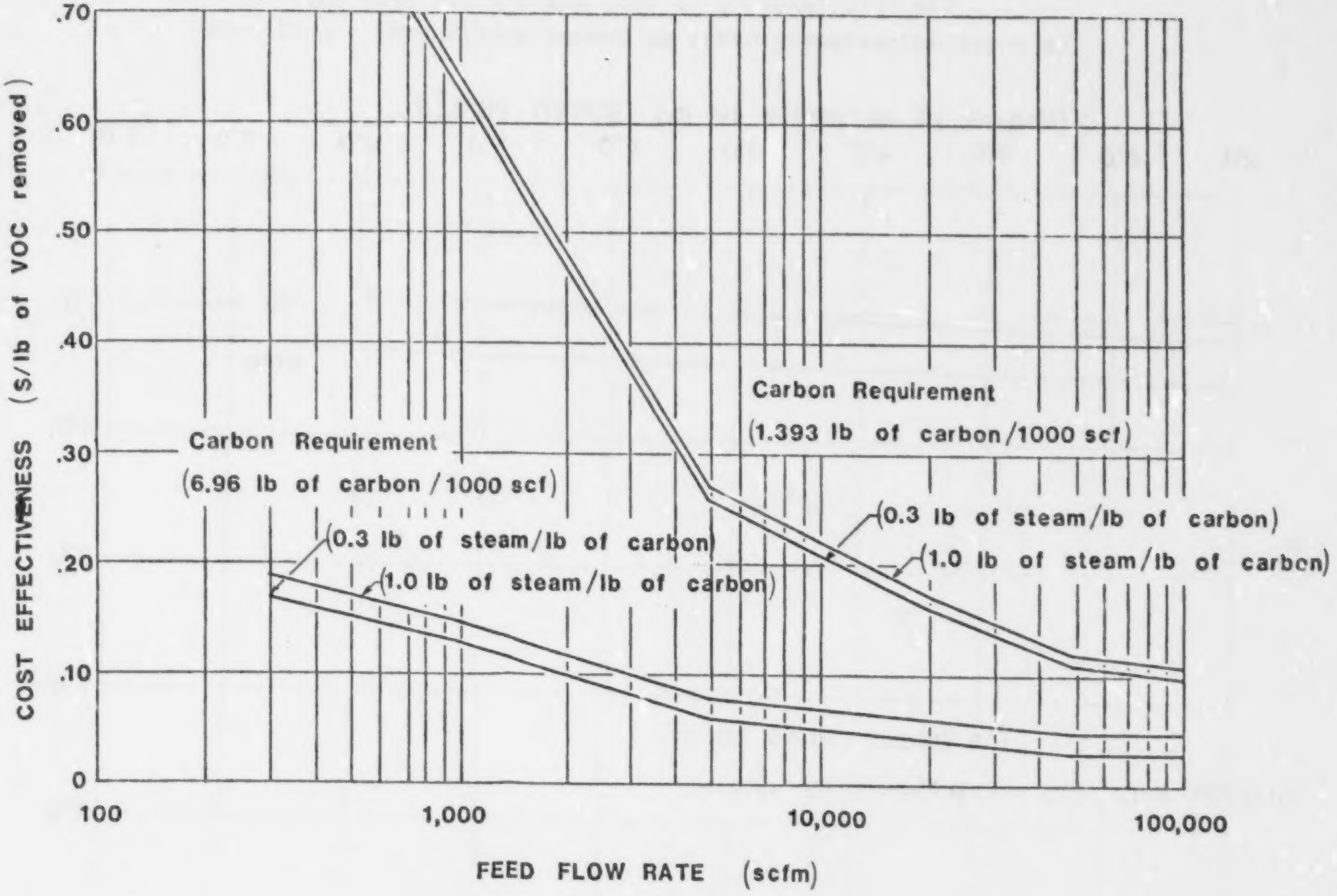
Carbon Requirement (lb of carbon/1000 scf)	Steam Energy Usage (Btu/scf) at		Energy Effectiveness (Btu/lb of VOC removed) at[a]	
	0.3 lb of Steam/ lb of Carbon[b]	1.0 lb of Steam/ lb of Carbon[c]	0.3 lb of steam/ lb of carbon[b]	1.0 lb of Steam/ lb of Carbon[c]
0.5 (∿359 ppm_v)[d]	0.146	0.485	3,627	10,035
1.393 (∿1000 ppm_v)[d]	0.405	1.35	3,127	9,809
6.96 (∿5000 ppm_v)[d]	2.03	6.75	2,957	9,722
10 (∿7180 ppm_v)[d]	2.91	9.70	2,939	9,716

[a] Does not include power requirements for blower.

[b] Assumes that a baseline effluent of 70 ppm_v can be achieved with 0.3 lb of steam/lb of carbon.

[c] Assumes that a baseline effluent of 12 ppm_v can be achieved with 1.0 lb of steam/lb of carbon.

[d] Assumes a VOC molecular weight of 50 and a carbon operating capacity of 0.10 lb of VOC/lb of carbon.



(For all cost-effectiveness calculations in this report a carbon capacity of 0.10 lb of VOC/lb of carbon is assumed. The carbon requirement per scf of waste gas is therefore dependent entirely on the VOC concentration in the process waste gas.
Adsorption effluent at 0.3 lb of steam/lb of carbon = 70 ppm_v of VOC.
Adsorption effluent at 1.0 lb of steam/lb of carbon = 12 ppm_v of VOC.)

Fig. IV-6. Cost Effectiveness vs Feed Rate at 1.393 and 6.96 lb of Carbon/1000 scf and a Steam Cost of $2.50 per Million Btu

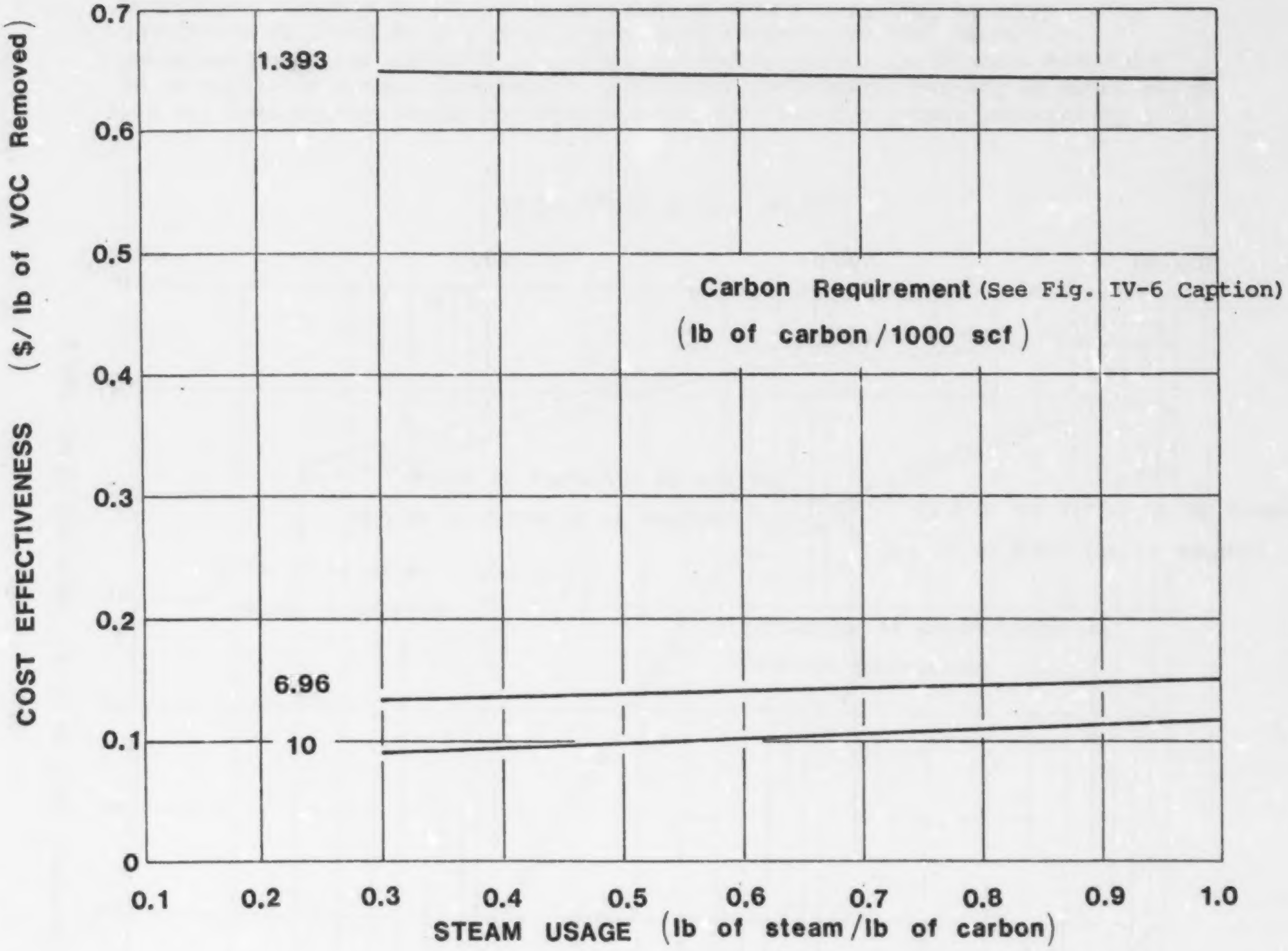


Fig. IV-7. Cost Effectiveness vs Steam Regeneration Rates at 1000 scfm and a Steam Cost of $2.50/Million Btu

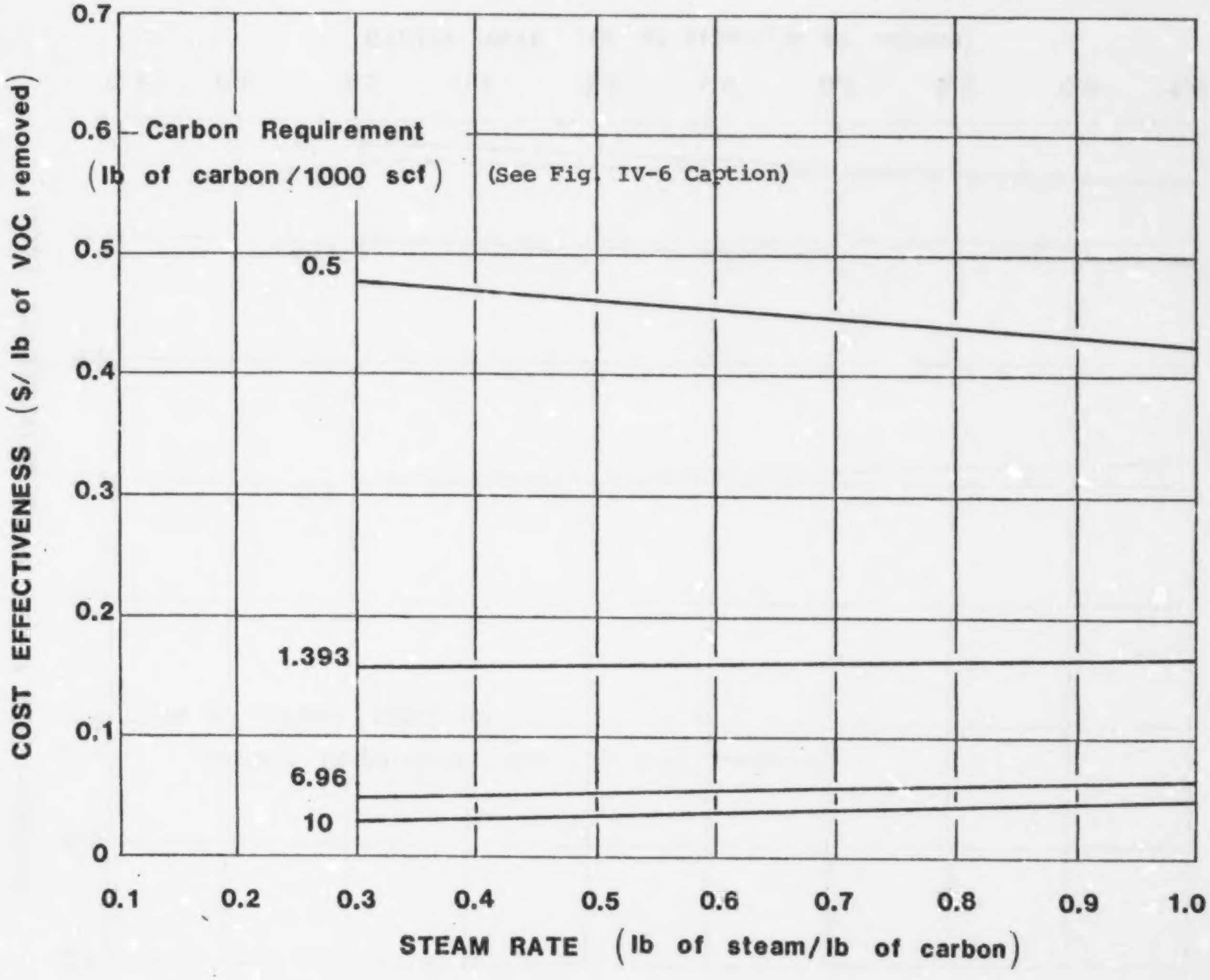


Fig. IV-8. Cost Effectiveness vs Steam Regeneration Rates at 20,000 scfm and a Steam Cost of $2.50/Million Btu

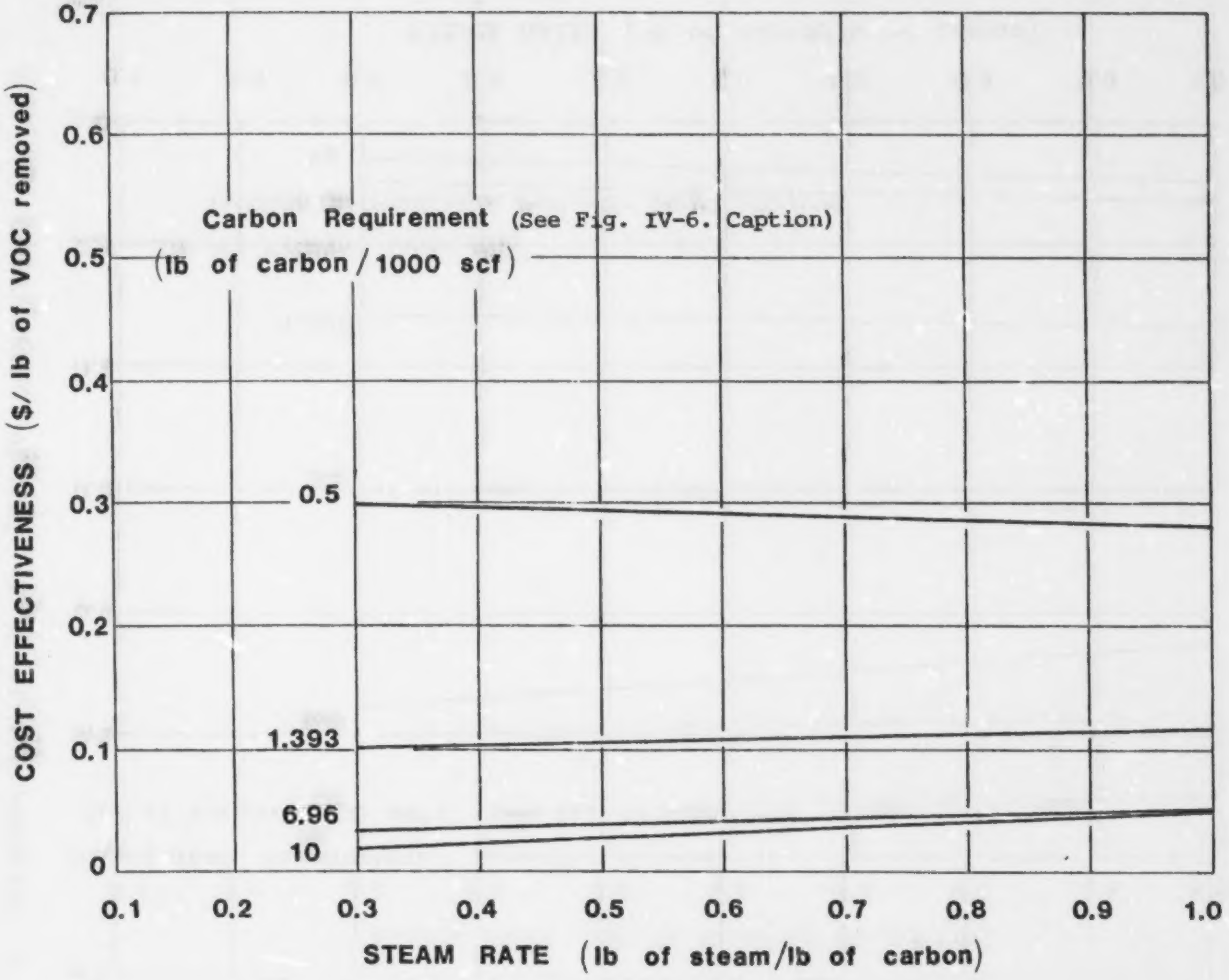


Fig. IV-9. Cost Effectiveness vs Steam Regeneration Rates at 100,000 scfm and a Steam Cost of $2.50/Million Btu

Table IV-6 shows the effect that increasing the steam regeneration required will have on cost and energy effectiveness. Data on cases not shown in the cited tables and figures can be easily developed by use of Appendix A. Table IV-6 also shows the percent change in cost effectiveness or energy effectiveness that results when the VOC removal efficiency is increased by increasing the steam regeneration usage from 0.3 lb of steam/lb of carbon regenerated to 1.0 lb of steam/lb of carbon regenerated for each waste-gas feed condition listed. It is assumed that a 70-ppm_v effluent concentration is achieved at a regeneration rate of 0.3 lb of steam/lb of carbon and that a 12-ppm_v effluent concentration is obtained at a regeneration rate of 1.0 lb of steam/lb of carbon.

This study does not quantitatively assess the impacts of the additional operations required to recover or treat the materials removed from the carbon adsorption system. When additional operations are required, secondary emissions, as well as increased capital costs and energy consumption, will have to be considered.

Table IV-6. Change in Cost Effectiveness and Energy Effectiveness with Increasing Regeneration Steam Usage

Carbon Requirement (lb of carbon/1000 scf)	Change in Cost Effectiveness[a] (%) at			Change in Energy Effectiveness[a] (%)
	1,000 scfm	20,000 scfm	100,000 scfm	
0.5 (∿359 ppm_v)[b]	-15	-10	-7	177
1.393 (∿1000 ppm_v)[b]	-16	6	10	213
6.96 (∿5000 ppm_v)[b]	15	50	67	229
10 (∿7180 ppm_v)[b]	22	67	100	231

[a] Change in regeneration steam requirement from 0.3 lb of steam/lb of carbon to 1.0 lb of steam/lb of carbon. The energy effectiveness (steam usage/lb of VOC removed) is independent of waste-gas flow rate.

[b] Assumes a carbon operating capacity of 0.1 lb of VOC/lb of carbon.

V. SUMMARY AND CONCLUSIONS

Carbon adsorption is a widely used control technique for VOC emissions. This evaluation describes the limits and design principles of carbon adsorption. A design criterion and design procedures are presented that allow for a preliminary carbon adsorption design. A carbon adsorption system with two bed depths and various steam regeneration rates is considered. Capital and operating costs are developed, and the annual cost of carbon adsorption is calculated as a function of the characteristics of the waste gas. Cost effectiveness and energy effectiveness of two VOC removal efficiencies and regeneration levels are developed.

The conclusions of the cost evaluation are as follows:

The feed flow rate is a highly sensitive variable in determining the annual cost and cost effectiveness (see Fig. IV-6). Energy effectiveness is independent of the flow rate. As the feed flow rate increases, the annual costs increase but the annual cost per scfm decreases. The annual cost per scfm decreases quickly between 300 and 5000 scfm. The ratio decreases moderately between 5,000 and 50,000 scfm and is almost constant above 50,000 scfm. The cost-effectiveness curve has the same shape as noted above.

The carbon requirement, which is established by the waste-gas VOC concentration and the operating capacity of the carbon, is a very sensitive variable in determining cost effectiveness (see Fig. IV-6). As the carbon requirement (VOC content) increases, the annual cost decreases with a corresponding reduction in the cost per pound of VOC removed. The energy effectiveness is fairly insensitive to changes in carbon requirements.

The cost effectiveness is strongly dependent on the value of the recovered material (see Table IV-3 and Appendix A). The fact that the VOC removed might be recycled or burned as a fuel is an important factor when carbon adsorption is considered as an emission control device candidate.

Annual cost and cost effectiveness are slightly sensitive to steam regeneration requirements (see Fig.s IV-6 through IV-9). The effect of the steam requirement on VOC removal cost is dependent on the carbon requirement. The higher the carbon requirement the more sensitive the steam regeneration rate is to VOC removal costs. At very low carbon requirements (low concentration of VOC in the process waste gas) a higher steam rate per pound of carbon may improve the adsorber emission enough so that the cost per pound of VOC removed is reduced.

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*Usually, when a reference is located at the end of a paragraph, it refers to the entire paragraph. If another reference relates to certain portions of that paragraph, that reference number is indicated on the material involved. When the reference appears on a heading, it refers to all the text covered by that heading.

APPENDIX A

ANNUAL COST DATA

ANNUAL COST DATA

The annual costs of carbon adsorption systems are presented in the following computer printouts showing costs for a specific carbon requirement and steam regeneration rate at various flow rates, steam costs, and recovery credits. The five credit levels shown correspond to the value of the VOC recovered at a specific carbon requirement. With a carbon operating capacity of 10 lb of VOC/100 lb of carbon assumed, the five credit levels correspond to \$0.00/lb of VOC, \$0.05/lb of VOC, \$0.10/lb of VOC, \$0.20/lb of VOC, and \$0.40/lb of VOC.

The following sample calculation is for a stream with a carbon requirement of 1.0 lb of carbon/1000 scf, a steam regeneration rate of 0.3 lb of steam/lb of carbon, a flow rate of 5000 scfm, and a credit value of \$0.05/lb of VOC at a carbon capacity of 0.10 lb of VOC/lb of carbon:

Capital cost = \$273,000 (from Fig. IV-1) at 5000 scfm with a 3-ft-deep bed.

Fixed cost = (\$273,000 X 0.29*) + carbon replacement cost (\$2,106) =
= \$81,276/yr.

Carbon replacement cost = (\$1.17*/lb of carbon) X

$$\text{X} \ \frac{(5000 \text{ scfm}) \text{ X } (3 \text{ ft deep}) \text{ X } (30 \text{ lb/ft}^3) \text{ X } 2 \text{ beds}}{(100 \text{ fpm}) \text{ X } (5^*\text{-yr replacement}^*)} = \$2{,}106/\text{yr}.$$

Utilities = steam (\$1,912) + electricity (\$4,925) + cooling water (\$331) = \$7,167/yr.

Steam = (0.3 lb of steam/lb of carbon) X (1 lb of carbon/1000 scf) X
X (5000 scfm) X (\$2.50*/million Btu) X (970 Btu/lb of steam) X
X (60 min/hr) X (8760 hr/yr) = \$1,912/yr

Blower electricity = (19.2 in. H_2O) X [0.000157 hp/(in. H_2O)(scfm)] X
X (1/0.60 efficiency) X [0.746(kWh/hr)/hp] X (5000 scfm) X (\$0.03*/kWh) X
X (8760 hr/yr = \$4,925/yr.

Condenser cooling water = (4.2 gal/lb of steam) X (0.3 lb of steam/lb of carbon) X (1 lb of carbon/1000 scf) X (5000 scfm) X (\$0.10/1000 gal*) X
X (60 min/hr) X (8760 hr/yr) = \$331/yr.

Credit = (\$0.05/lb of VOC) X (1 lb of carbon/1000 scf) X (0.10 lb of VOC/lb of carbon) X (5000 scfm) X (60 min/hr) X (8760 hr/yr) =
= \$13,140/yr.

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*See Table IV-2.

Annual cost = fixed cost ($81,276) + utilities ($7,167) - credit ($13,140)
= $75,303/yr.

Net cost = annual cost ($75,303)/flow rate (5000 scfm) = $15.06/scfm.

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.51
	1000.	144.	42.	1.	0.	43.	43.21
	5000.	273.	81.	5.	0.	86.	17.28
	20000.	594.	179.	21.	0.	199.	9.95
	50000.	955.	293.	51.	0.	344.	6.88
	100000.	1671.	513.	103.	0.	615.	6.15
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.25
	1000.	144.	42.	1.	0.	43.	42.94
	5000.	273.	81.	5.	1.	85.	17.02
	20000.	594.	179.	21.	5.	194.	9.69
	50000.	955.	293.	51.	13.	331.	6.62
	100000.	1671.	513.	103.	26.	589.	5.89
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.99
	1000.	144.	42.	1.	1.	43.	42.68
	5000.	273.	81.	5.	3.	84.	16.75
	20000.	594.	179.	21.	11.	189.	9.43
	50000.	955.	293.	51.	26.	318.	6.35
	100000.	1671.	513.	103.	53.	563.	5.63
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.46
	1000.	144.	42.	1.	1.	42.	42.16
	5000.	273.	81.	5.	5.	81.	16.23
	20000.	594.	179.	21.	21.	178.	8.90
	50000.	955.	293.	51.	53.	291.	5.83
	100000.	1671.	513.	103.	105.	510.	5.10
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.41
	1000.	144.	42.	1.	2.	41.	41.10
	5000.	273.	81.	5.	11.	76.	15.18
	20000.	594.	179.	21.	42.	157.	7.85
	50000.	955.	293.	51.	105.	239.	4.78
	100000.	1671.	513.	103.	210.	405.	4.05

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	OPERATING COST-OR-CREDIT RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.56
	1000.	144.	42.	1.	0.	43.	43.25
	5000.	273.	81.	5.	0.	87.	17.33
	20000.	594.	179.	21.	0.	200.	10.00
	50000.	955.	293.	53.	0.	346.	6.92
	100000.	1671.	513.	107.	0.	620.	6.20
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.30
	1000.	144.	42.	1.	0.	43.	42.99
	5000.	273.	81.	5.	1.	85.	17.06
	20000.	594.	179.	21.	5.	195.	9.74
	50000.	955.	293.	53.	13.	333.	6.66
	100000.	1671.	513.	107.	26.	593.	5.93
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.03
	1000.	144.	42.	1.	1.	43.	42.73
	5000.	273.	81.	5.	3.	84.	16.80
	20000.	594.	179.	21.	11.	189.	9.47
	50000.	955.	293.	53.	26.	320.	6.40
	100000.	1671.	513.	107.	53.	567.	5.67
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.51
	1000.	144.	42.	1.	1.	42.	42.20
	5000.	273.	81.	5.	5.	81.	16.27
	20000.	594.	179.	21.	21.	179.	8.95
	50000.	955.	293.	53.	53.	294.	5.87
	100000.	1671.	513.	107.	105.	514.	5.14
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.46
	1000.	144.	42.	1.	2.	41.	41.15
	5000.	273.	81.	5.	11.	76.	15.22
	20000.	594.	179.	21.	42.	158.	7.90
	50000.	955.	293.	53.	105.	241.	4.82
	100000.	1671.	513.	107.	210.	409.	4.09

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.62
	1000.	144.	42.	1.	0.	43.	43.31
	5000.	273.	81.	6.	0.	87.	17.38
	20000.	594.	179.	23.	0.	201.	10.06
	50000.	955.	293.	56.	0.	349.	6.98
	100000.	1671.	513.	113.	0.	626.	6.26
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.35
	1000.	144.	42.	1.	0.	43.	43.05
	5000.	273.	81.	6.	1.	86.	17.12
	20000.	594.	179.	23.	5.	196.	9.80
	50000.	955.	293.	56.	13.	336.	6.72
	100000.	1671.	513.	113.	26.	599.	5.99
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.09
	1000.	144.	42.	1.	1.	43.	42.79
	5000.	273.	81.	6.	3.	84.	16.86
	20000.	594.	179.	23.	11.	191.	9.53
	50000.	955.	293.	56.	26.	323.	6.46
	100000.	1671.	513.	113.	53.	573.	5.73
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.57
	1000.	144.	42.	1.	1.	42.	42.26
	5000.	273.	81.	6.	5.	82.	16.33
	20000.	594.	179.	23.	21.	180.	9.01
	50000.	955.	293.	56.	53.	297.	5.93
	100000.	1671.	513.	113.	105.	520.	5.20
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.52
	1000.	144.	42.	1.	2.	41.	41.21
	5000.	273.	81.	6.	11.	76.	15.28
	20000.	594.	179.	23.	42.	159.	7.96
	50000.	955.	293.	56.	105.	244.	4.88
	100000.	1671.	513.	113.	210.	415.	4.15

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.77
	1000.	144.	42.	1.	0.	43.	43.46
	5000.	273.	81.	6.	0.	88.	17.53
	20000.	594.	179.	26.	0.	204.	10.21
	50000.	955.	293.	64.	0.	357.	7.13
	100000.	1671.	513.	128.	0.	641.	6.41
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.50
	1000.	144.	42.	1.	0.	43.	43.20
	5000.	273.	81.	6.	1.	86.	17.27
	20000.	594.	179.	26.	5.	199.	9.95
	50000.	955.	293.	64.	13.	344.	6.87
	100000.	1671.	513.	128.	26.	614.	6.14
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.24
	1000.	144.	42.	1.	1.	43.	42.93
	5000.	273.	81.	6.	3.	85.	17.01
	20000.	594.	179.	26.	11.	194.	9.68
	50000.	955.	293.	64.	26.	330.	6.61
	100000.	1671.	513.	128.	53.	588.	5.88
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.72
	1000.	144.	42.	1.	1.	42.	42.41
	5000.	273.	81.	6.	5.	82.	16.48
	20000.	594.	179.	26.	21.	183.	9.16
	50000.	955.	293.	64.	53.	304.	6.08
	100000.	1671.	513.	128.	105.	535.	5.35
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.66
	1000.	144.	42.	1.	2.	41.	41.36
	5000.	273.	81.	6.	11.	77.	15.43
	20000.	594.	179.	26.	42.	162.	8.11
	50000.	955.	293.	64.	105.	252.	5.03
	100000.	1671.	513.	128.	210.	430.	4.30

OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.69
	1000.	144.	42.	1.	0.	43.	43.39
	5000.	273.	81.	6.	0.	87.	17.46
	20000.	594.	179.	24.	0.	203.	10.13
	50000.	955.	293.	60.	0.	353.	7.06
	100000.	1671.	513.	120.	0.	633.	6.33
0.0025$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.38
	1000.	144.	42.	1.	1.	42.	42.07
	5000.	273.	81.	6.	7.	81.	16.15
	20000.	594.	179.	24.	26.	176.	8.82
	50000.	955.	293.	60.	66.	287.	5.75
	100000.	1671.	513.	120.	131.	502.	5.02
0.0050$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.06
	1000.	144.	42.	1.	3.	41.	40.76
	5000.	273.	81.	6.	13.	74.	14.83
	20000.	594.	179.	24.	53.	150.	7.51
	50000.	955.	293.	60.	131.	222.	4.43
	100000.	1671.	513.	120.	263.	370.	3.70
0.0100$/1000 SCF							
	300.	58.	17.	0.	2.	16.	52.44
	1000.	144.	42.	1.	5.	38.	38.13
	5000.	273.	81.	6.	26.	61.	12.20
	20000.	594.	179.	24.	105.	98.	4.88
	50000.	955.	293.	60.	263.	90.	1.80
	100000.	1671.	513.	120.	526.	107.	1.07
0.0200$/1000 SCF							
	300.	58.	17.	0.	3.	14.	47.18
	1000.	144.	42.	1.	11.	33.	32.87
	5000.	273.	81.	6.	53.	35.	6.95
	20000.	594.	179.	24.	210.	-8.	-0.38
	50000.	955.	293.	60.	526.	-173.	-3.45
	100000.	1671.	513.	120.	1051.	-418.	-4.18

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OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.92
	1000.	144.	42.	1.	0.	44.	43.61
	5000.	273.	81.	7.	0.	88.	17.68
	20000.	594.	179.	29.	0.	207.	10.36
	50000.	955.	293.	71.	0.	364.	7.28
	100000.	1671.	513.	143.	0.	655.	6.55
0.0025$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.60
	1000.	144.	42.	1.	1.	42.	42.30
	5000.	273.	81.	7.	7.	82.	16.37
	20000.	594.	179.	29.	26.	181.	9.04
	50000.	955.	293.	71.	66.	298.	5.97
	100000.	1671.	513.	143.	131.	524.	5.24
0.0050$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.29
	1000.	144.	42.	1.	3.	41.	40.98
	5000.	273.	81.	7.	13.	75.	15.06
	20000.	594.	179.	29.	53.	155.	7.73
	50000.	955.	293.	71.	131.	233.	4.66
	100000.	1671.	513.	143.	263.	393.	3.93
0.0100$/1000 SCF							
	300.	58.	17.	0.	2.	16.	52.66
	1000.	144.	42.	1.	5.	38.	38.35
	5000.	273.	81.	7.	26.	62.	12.43
	20000.	594.	179.	29.	105.	102.	5.10
	50000.	955.	293.	71.	263.	101.	2.03
	100000.	1671.	513.	143.	526.	130.	1.30
0.0200$/1000 SCF							
	300.	58.	17.	0.	3.	14.	47.40
	1000.	144.	42.	1.	11.	33.	33.10
	5000.	273.	81.	7.	53.	36.	7.17
	20000.	594.	179.	29.	210.	-3.	-0.15
	50000.	955.	293.	71.	526.	-161.	-3.23
	100000.	1671.	513.	143.	1051.	-396.	-3.96

OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	17.	58.22
	1000.	144.	42.	2.	0.	44.	43.91
	5000.	273.	81.	9.	0.	90.	17.98
	20000.	594.	179.	35.	0.	213.	10.66
	50000.	955.	293.	86.	0.	379.	7.58
	100000.	1671.	513.	173.	0.	685.	6.85
0.0025$/1000 SCF							
	300.	58.	17.	1.	0.	17.	56.90
	1000.	144.	42.	2.	1.	43.	42.60
	5000.	273.	81.	9.	7.	83.	16.67
	20000.	594.	179.	35.	26.	187.	9.34
	50000.	955.	293.	86.	66.	313.	6.27
	100000.	1671.	513.	173.	131.	554.	5.54
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	55.59
	1000.	144.	42.	2.	3.	41.	41.28
	5000.	273.	81.	9.	13.	77.	15.36
	20000.	594.	179.	35.	53.	161.	8.03
	50000.	955.	293.	86.	131.	248.	4.95
	100000.	1671.	513.	173.	263.	423.	4.23
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	52.96
	1000.	144.	42.	2.	5.	39.	38.65
	5000.	273.	81.	9.	26.	64.	12.73
	20000.	594.	179.	35.	105.	108.	5.40
	50000.	955.	293.	86.	263.	116.	2.33
	100000.	1671.	513.	173.	526.	160.	1.60
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	14.	47.70
	1000.	144.	42.	2.	11.	33.	33.40
	5000.	273.	81.	9.	53.	37.	7.47
	20000.	594.	179.	35.	210.	3.	0.14
	50000.	955.	293.	86.	526.	-146.	-2.93
	100000.	1671.	513.	173.	1051.	-366.	-3.66

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OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	58.96
	1000.	144.	42.	2.	0.	45.	44.66
	5000.	273.	81.	12.	0.	94.	18.73
	20000.	594.	179.	50.	0.	228.	11.40
	50000.	955.	293.	124.	0.	417.	8.33
	100000.	1671.	513.	248.	0.	760.	7.60
0.0025$/1000 SCF	300.	58.	17.	1.	0.	17.	57.65
	1000.	144.	42.	2.	1.	43.	43.34
	5000.	273.	81.	12.	7.	87.	17.42
	20000.	594.	179.	50.	26.	202.	10.09
	50000.	955.	293.	124.	66.	351.	7.02
	100000.	1671.	513.	248.	131.	629.	6.29
0.0050$/1000 SCF	300.	58.	17.	1.	1.	17.	56.34
	1000.	144.	42.	2.	3.	42.	42.03
	5000.	273.	81.	12.	13.	81.	16.10
	20000.	594.	179.	50.	53.	176.	8.78
	50000.	955.	293.	124.	131.	285.	5.70
	100000.	1671.	513.	248.	263.	497.	4.97
0.0100$/1000 SCF	300.	58.	17.	1.	2.	16.	53.71
	1000.	144.	42.	2.	5.	39.	39.40
	5000.	273.	81.	12.	26.	67.	13.47
	20000.	594.	179.	50.	105.	123.	6.15
	50000.	955.	293.	124.	263.	154.	3.07
	100000.	1671.	513.	248.	526.	235.	2.35
0.0200$/1000 SCF	300.	58.	17.	1.	3.	15.	48.45
	1000.	144.	42.	2.	11.	34.	34.14
	5000.	273.	81.	12.	53.	41.	8.22
	20000.	594.	179.	50.	210.	18.	0.89
	50000.	955.	293.	124.	526.	-109.	-2.18
	100000.	1671.	513.	248.	1051.	-291.	-2.91

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	OPERATING COST-OR-CREDIT RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.92
	1000.	144.	42.	1.	0.	44.	43.61
	5000.	273.	81.	7.	0.	88.	17.68
	20000.	594.	179.	29.	0.	207.	10.36
	50000.	955.	293.	71.	0.	364.	7.28
	100000.	1671.	513.	143.	0.	655.	6.55
0.0050$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.29
	1000.	144.	42.	1.	3.	41.	40.98
	5000.	273.	81.	7.	13.	75.	15.06
	20000.	594.	179.	29.	53.	155.	7.73
	50000.	955.	293.	71.	131.	233.	4.66
	100000.	1671.	513.	143.	263.	393.	3.93
0.0100$/1000 SCF							
	300.	58.	17.	0.	2.	16.	52.66
	1000.	144.	42.	1.	5.	38.	38.35
	5000.	273.	81.	7.	26.	62.	12.43
	20000.	594.	179.	29.	105.	102.	5.10
	50000.	955.	293.	71.	263.	101.	2.03
	100000.	1671.	513.	143.	526.	130.	1.30
0.0200$/1000 SCF							
	300.	58.	17.	0.	3.	14.	47.40
	1000.	144.	42.	1.	11.	33.	33.10
	5000.	273.	81.	7.	53.	36.	7.17
	20000.	594.	179.	29.	210.	-3.	-0.15
	50000.	955.	293.	71.	526.	-161.	-3.23
	100000.	1671.	513.	143.	1051.	-396.	-3.96
0.0400$/1000 SCF							
	300.	58.	17.	0.	6.	11.	36.89
	1000.	144.	42.	1.	21.	23.	22.59
	5000.	273.	81.	7.	105.	-17.	-3.34
	20000.	594.	179.	29.	420.	-213.	-10.67
	50000.	955.	293.	71.	1051.	-687.	-13.74
	100000.	1671.	513.	143.	2102.	-1447.	-14.47

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	OPERATING COST-OR-CREDIT RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	58.37
	1000.	144.	42.	2.	0.	44.	44.06
	5000.	273.	81.	9.	0.	91.	18.13
	20000.	594.	179.	38.	0.	216.	10.81
	50000.	955.	293.	94.	0.	387.	7.73
	100000.	1671.	513.	188.	0.	700.	7.00
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	55.74
	1000.	144.	42.	2.	3.	41.	41.43
	5000.	273.	81.	9.	13.	78.	15.50
	20000.	594.	179.	38.	53.	164.	8.18
	50000.	955.	293.	94.	131.	255.	5.10
	100000.	1671.	513.	188.	263.	438.	4.38
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.11
	1000.	144.	42.	2.	5.	39.	38.80
	5000.	273.	81.	9.	26.	64.	12.88
	20000.	594.	179.	38.	105.	111.	5.55
	50000.	955.	293.	94.	263.	124.	2.48
	100000.	1671.	513.	188.	526.	175.	1.75
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	14.	47.85
	1000.	144.	42.	2.	11.	34.	33.55
	5000.	273.	81.	9.	53.	38.	7.62
	20000.	594.	179.	38.	210.	6.	0.29
	50000.	955.	293.	94.	526.	-139.	-2.78
	100000.	1671.	513.	188.	1051.	-351.	-3.51
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	11.	37.34
	1000.	144.	42.	2.	21.	23.	23.03
	5000.	273.	81.	9.	105.	-14.	-2.89
	20000.	594.	179.	38.	420.	-204.	-10.22
	50000.	955.	293.	94.	1051.	-665.	-13.29
	100000.	1671.	513.	188.	2102.	-1402.	-14.02

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	58.96
	1000.	144.	42.	2.	0.	45.	44.66
	5000.	273.	81.	12.	0.	94.	18.73
	20000.	594.	179.	50.	0.	228.	11.40
	50000.	955.	293.	124.	0.	417.	8.33
	100000.	1671.	513.	248.	0.	760.	7.60
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	56.34
	1000.	144.	42.	2.	3.	42.	42.03
	5000.	273.	81.	12.	13.	81.	16.10
	20000.	594.	179.	50.	53.	176.	8.78
	50000.	955.	293.	124.	131.	285.	5.70
	100000.	1671.	513.	248.	263.	497.	4.97
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.71
	1000.	144.	42.	2.	5.	39.	39.40
	5000.	273.	81.	12.	26.	67.	13.47
	20000.	594.	179.	50.	105.	123.	6.15
	50000.	955.	293.	124.	263.	154.	3.07
	100000.	1671.	513.	248.	526.	235.	2.35
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	15.	48.45
	1000.	144.	42.	2.	11.	34.	34.14
	5000.	273.	81.	12.	53.	41.	8.22
	20000.	594.	179.	50.	210.	18.	0.89
	50000.	955.	293.	124.	526.	-109.	-2.18
	100000.	1671.	513.	248.	1051.	-291.	-2.91
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	11.	37.94
	1000.	144.	42.	2.	21.	24.	23.63
	5000.	273.	81.	12.	105.	-11.	-2.29
	20000.	594.	179.	50.	420.	-192.	-9.62
	50000.	955.	293.	124.	1051.	-635.	-12.69
	100000.	1671.	513.	248.	2102.	-1342.	-13.42

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	60.46
	1000.	144.	42.	4.	0.	46.	46.15
	5000.	273.	81.	20.	0.	101.	20.23
	20000.	594.	179.	79.	0.	258.	12.90
	50000.	955.	293.	199.	0.	491.	9.83
	100000.	1671.	513.	397.	0.	910.	9.10
0.0050$/1000 SCF	300.	58.	17.	1.	1.	17.	57.83
	1000.	144.	42.	4.	3.	44.	43.52
	5000.	273.	81.	20.	13.	88.	17.60
	20000.	594.	179.	79.	53.	205.	10.27
	50000.	955.	293.	199.	131.	360.	7.20
	100000.	1671.	513.	397.	263.	647.	6.47
0.0100$/1000 SCF	300.	58.	17.	1.	2.	17.	55.20
	1000.	144.	42.	4.	5.	41.	40.90
	5000.	273.	81.	20.	26.	75.	14.97
	20000.	594.	179.	79.	105.	153.	7.64
	50000.	955.	293.	199.	263.	228.	4.57
	100000.	1671.	513.	397.	526.	384.	3.84
0.0200$/1000 SCF	300.	58.	17.	1.	3.	15.	49.95
	1000.	144.	42.	4.	11.	36.	35.64
	5000.	273.	81.	20.	53.	49.	9.71
	20000.	594.	179.	79.	210.	48.	2.39
	50000.	955.	293.	199.	526.	-34.	-0.69
	100000.	1671.	513.	397.	1051.	-142.	-1.42
0.0400$/1000 SCF	300.	58.	17.	1.	6.	12.	39.43
	1000.	144.	42.	4.	21.	25.	25.13
	5000.	273.	81.	20.	105.	-4.	-0.80
	20000.	594.	179.	79.	420.	-162.	-8.12
	50000.	955.	293.	199.	1051.	-560.	-11.20
	100000.	1671.	513.	397.	2102.	-1193.	-11.93

OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	58.09
	1000.	144.	42.	2.	0.	44.	43.79
	5000.	273.	81.	8.	0.	89.	17.86
	20000.	594.	179.	32.	0.	211.	10.53
	50000.	955.	293.	80.	0.	373.	7.46
	100000.	1671.	513.	161.	0.	673.	6.73
0.0070$/1000 SCF							
	300.	58.	17.	0.	1.	16.	54.43
	1000.	144.	42.	2.	4.	40.	40.13
	5000.	273.	81.	8.	18.	71.	14.20
	20000.	594.	179.	32.	73.	137.	6.87
	50000.	955.	293.	80.	183.	190.	3.80
	100000.	1671.	513.	161.	366.	307.	3.07
0.0139$/1000 SCF							
	300.	58.	17.	0.	2.	15.	50.77
	1000.	144.	42.	2.	7.	36.	36.46
	5000.	273.	81.	8.	37.	53.	10.54
	20000.	594.	179.	32.	146.	64.	3.21
	50000.	955.	293.	80.	366.	7.	0.14
	100000.	1671.	513.	161.	732.	-59.	-0.59
0.0279$/1000 SCF							
	300.	58.	17.	0.	4.	13.	43.45
	1000.	144.	42.	2.	15.	29.	29.14
	5000.	273.	81.	8.	73.	16.	3.22
	20000.	594.	179.	32.	293.	-82.	-4.11
	50000.	955.	293.	80.	732.	-359.	-7.18
	100000.	1671.	513.	161.	1464.	-791.	-7.91
0.0557$/1000 SCF							
	300.	58.	17.	0.	9.	9.	28.81
	1000.	144.	42.	2.	29.	14.	14.50
	5000.	273.	81.	8.	146.	-57.	-11.43
	20000.	594.	179.	32.	586.	-375.	-18.75
	50000.	955.	293.	80.	1464.	-1091.	-21.83
	100000.	1671.	513.	161.	2929.	-2256.	-22.56

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OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	58.72
	1000.	144.	42.	2.	0.	44.	44.41
	5000.	273.	81.	11.	0.	92.	18.49
	20000.	594.	179.	45.	0.	223.	11.16
	50000.	955.	293.	112.	0.	404.	8.08
	100000.	1671.	513.	223.	0.	736.	7.36
0.0070$/1000 SCF							
	300.	58.	17.	1.	1.	17.	55.06
	1000.	144.	42.	2.	4.	41.	40.75
	5000.	273.	81.	11.	18.	74.	14.82
	20000.	594.	179.	45.	73.	150.	7.50
	50000.	955.	293.	112.	183.	221.	4.42
	100000.	1671.	513.	223.	366.	370.	3.70
0.0139$/1000 SCF							
	300.	58.	17.	1.	2.	15.	51.40
	1000.	144.	42.	2.	7.	37.	37.09
	5000.	273.	81.	11.	37.	56.	11.16
	20000.	594.	179.	45.	146.	77.	3.84
	50000.	955.	293.	112.	366.	38.	0.76
	100000.	1671.	513.	223.	732.	3.	0.03
0.0279$/1000 SCF							
	300.	58.	17.	1.	4.	13.	44.07
	1000.	144.	42.	2.	15.	30.	29.77
	5000.	273.	81.	11.	73.	19.	3.84
	20000.	594.	179.	45.	293.	-70.	-3.48
	50000.	955.	293.	112.	732.	-328.	-6.56
	100000.	1671.	513.	223.	1464.	-729.	-7.29
0.0557$/1000 SCF							
	300.	58.	17.	1.	9.	9.	29.43
	1000.	144.	42.	2.	29.	15.	15.12
	5000.	273.	81.	11.	146.	-54.	-10.80
	20000.	594.	179.	45.	586.	-363.	-18.13
	50000.	955.	293.	112.	1464.	-1060.	-21.20
	100000.	1671.	513.	223.	2929.	-2193.	-21.93

OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	59.55
	1000.	144.	42.	3.	0.	45.	45.24
	5000.	273.	81.	15.	0.	97.	19.32
	20000.	594.	179.	61.	0.	240.	11.99
	50000.	955.	293.	153.	0.	446.	8.92
	100000.	1671.	513.	306.	0.	819.	8.19
0.0070$/1000 SCF							
	300.	58.	17.	1.	1.	17.	55.89
	1000.	144.	42.	3.	4.	42.	41.58
	5000.	273.	81.	15.	18.	78.	15.66
	20000.	594.	179.	61.	73.	167.	8.33
	50000.	955.	293.	153.	183.	263.	5.26
	100000.	1671.	513.	306.	366.	453.	4.53
0.0139$/1000 SCF							
	300.	58.	17.	1.	2.	16.	52.23
	1000.	144.	42.	3.	7.	38.	37.92
	5000.	273.	81.	15.	37.	60.	12.00
	20000.	594.	179.	61.	146.	93.	4.67
	50000.	955.	293.	153.	366.	80.	1.60
	100000.	1671.	513.	306.	732.	87.	0.87
0.0279$/1000 SCF							
	300.	58.	17.	1.	4.	13.	44.91
	1000.	144.	42.	3.	15.	31.	30.60
	5000.	273.	81.	15.	73.	23.	4.68
	20000.	594.	179.	61.	293.	-53.	-2.65
	50000.	955.	293.	153.	732.	-286.	-5.73
	100000.	1671.	513.	306.	1464.	-645.	-6.45
0.0557$/1000 SCF							
	300.	58.	17.	1.	9.	9.	30.26
	1000.	144.	42.	3.	29.	16.	15.96
	5000.	273.	81.	15.	146.	-50.	-9.97
	20000.	594.	179.	61.	586.	-346.	-17.29
	50000.	955.	293.	153.	1464.	-1018.	-20.37
	100000.	1671.	513.	306.	2929.	-2110.	-21.10

OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT			NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
			FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)		
0.0000$/1000 SCF							
	300.	58.	17.	2.	0.	18.	61.63
	1000.	144.	42.	5.	0.	47.	47.33
	5000.	273.	81.	26.	0.	107.	21.40
	20000.	594.	179.	103.	0.	282.	14.08
	50000.	955.	293.	257.	0.	550.	11.00
	100000.	1671.	513.	515.	0.	1027.	10.27
0.0070$/1000 SCF							
	300.	58.	17.	2.	1.	17.	57.97
	1000.	144.	42.	5.	4.	44.	43.67
	5000.	273.	81.	26.	18.	89.	17.74
	20000.	594.	179.	103.	73.	208.	10.41
	50000.	955.	293.	257.	183.	367.	7.34
	100000.	1671.	513.	515.	366.	661.	6.61
0.0139$/1000 SCF							
	300.	58.	17.	2.	2.	16.	54.31
	1000.	144.	42.	5.	7.	40.	40.01
	5000.	273.	81.	26.	37.	70.	14.08
	20000.	594.	179.	103.	146.	135.	6.75
	50000.	955.	293.	257.	366.	184.	3.68
	100000.	1671.	513.	515.	732.	295.	2.95
0.0279$/1000 SCF							
	300.	58.	17.	2.	4.	14.	46.99
	1000.	144.	42.	5.	15.	33.	32.68
	5000.	273.	81.	26.	73.	34.	6.76
	20000.	594.	179.	103.	293.	-11.	-0.57
	50000.	955.	293.	257.	732.	-182.	-3.64
	100000.	1671.	513.	515.	1464.	-437.	-4.37
0.0557$/1000 SCF							
	300.	58.	17.	2.	9.	10.	32.35
	1000.	144.	42.	5.	29.	18.	18.04
	5000.	273.	81.	26.	146.	-39.	-7.88
	20000.	594.	179.	103.	586.	-304.	-15.21
	50000.	955.	293.	257.	1464.	-914.	-18.29
	100000.	1671.	513.	515.	2929.	-1901.	-19.01

OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	58.37
	1000.	144.	42.	2.	0.	44.	44.06
	5000.	273.	81.	9.	0.	91.	18.13
	20000.	594.	179.	38.	0.	216.	10.81
	50000.	955.	293.	94.	0.	387.	7.73
	100000.	1671.	513.	188.	0.	700.	7.00
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.11
	1000.	144.	42.	2.	5.	39.	38.80
	5000.	273.	81.	9.	26.	64.	12.88
	20000.	594.	179.	38.	105.	111.	5.55
	50000.	955.	293.	94.	263.	124.	2.48
	100000.	1671.	513.	188.	526.	175.	1.75
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	14.	47.85
	1000.	144.	42.	2.	11.	34.	33.55
	5000.	273.	81.	9.	53.	38.	7.62
	20000.	594.	179.	38.	210.	6.	0.29
	50000.	955.	293.	94.	526.	-139.	-2.78
	100000.	1671.	513.	188.	1051.	-351.	-3.51
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	11.	37.34
	1000.	144.	42.	2.	21.	23.	23.03
	5000.	273.	81.	9.	105.	-14.	-2.89
	20000.	594.	179.	38.	420.	-204.	-10.22
	50000.	955.	293.	94.	1051.	-665.	-13.29
	100000.	1671.	513.	188.	2102.	-1402.	-14.02
0.0800$/1000 SCF							
	300.	58.	17.	1.	13.	5.	16.32
	1000.	144.	42.	2.	42.	2.	2.01
	5000.	273.	81.	9.	210.	-120.	-23.92
	20000.	594.	179.	38.	841.	-625.	-31.24
	50000.	955.	293.	94.	2102.	-1716.	-34.32
	100000.	1671.	513.	188.	4205.	-3504.	-35.04

OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	59.26
	1000.	144.	42.	3.	0.	45.	44.96
	5000.	273.	81.	14.	0.	95.	19.03
	20000.	594.	179.	55.	0.	234.	11.70
	50000.	955.	293.	139.	0.	431.	8.63
	100000.	1671.	513.	277.	0.	790.	7.90
0.0100$/1000 SCF	300.	58.	17.	1.	2.	16.	54.01
	1000.	144.	42.	3.	5.	40.	39.70
	5000.	273.	81.	14.	26.	69.	13.77
	20000.	594.	179.	55.	105.	129.	6.45
	50000.	955.	293.	139.	263.	169.	3.37
	100000.	1671.	513.	277.	526.	264.	2.64
0.0200$/1000 SCF	300.	58.	17.	1.	3.	15.	48.75
	1000.	144.	42.	3.	11.	34.	34.44
	5000.	273.	81.	14.	53.	43.	8.52
	20000.	594.	179.	55.	210.	24.	1.19
	50000.	955.	293.	139.	526.	-94.	-1.88
	100000.	1671.	513.	277.	1051.	-261.	-2.61
0.0400$/1000 SCF	300.	58.	17.	1.	6.	11.	38.24
	1000.	144.	42.	3.	21.	24.	23.93
	5000.	273.	81.	14.	105.	-10.	-1.99
	20000.	594.	179.	55.	420.	-186.	-9.32
	50000.	955.	293.	139.	1051.	-620.	-12.39
	100000.	1671.	513.	277.	2102.	-1312.	-13.12
0.0800$/1000 SCF	300.	58.	17.	1.	13.	5.	17.21
	1000.	144.	42.	3.	42.	3.	2.91
	5000.	273.	81.	14.	210.	-115.	-23.02
	20000.	594.	179.	55.	841.	-607.	-30.34
	50000.	955.	293.	139.	2102.	-1671.	-33.42
	100000.	1671.	513.	277.	4205.	-3415.	-34.15

OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	OPERATING COST-OR-CREDIT RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	60.46
	1000.	144.	42.	4.	0.	46.	46.15
	5000.	273.	81.	20.	0.	101.	20.23
	20000.	594.	179.	79.	0.	258.	12.90
	50000.	955.	293.	199.	0.	491.	9.83
	100000.	1671.	513.	397.	0.	910.	9.10
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	17.	55.20
	1000.	144.	42.	4.	5.	41.	40.90
	5000.	273.	81.	20.	26.	75.	14.97
	20000.	594.	179.	79.	105.	153.	7.64
	50000.	955.	293.	199.	263.	228.	4.57
	100000.	1671.	513.	397.	526.	384.	3.84
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	15.	49.95
	1000.	144.	42.	4.	11.	36.	35.64
	5000.	273.	81.	20.	53.	49.	9.71
	20000.	594.	179.	79.	210.	48.	2.39
	50000.	955.	293.	199.	526.	-34.	-0.69
	100000.	1671.	513.	397.	1051.	-142.	-1.42
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	12.	39.43
	1000.	144.	42.	4.	21.	25.	25.13
	5000.	273.	81.	20.	105.	-4.	-0.80
	20000.	594.	179.	79.	420.	-162.	-8.12
	50000.	955.	293.	199.	1051.	-560.	-11.20
	100000.	1671.	513.	397.	2102.	-1193.	-11.93
0.0800$/1000 SCF							
	300.	58.	17.	1.	13.	6.	18.41
	1000.	144.	42.	4.	42.	4.	4.10
	5000.	273.	81.	20.	210.	-109.	-21.82
	20000.	594.	179.	79.	841.	-583.	-29.15
	50000.	955.	293.	199.	2102.	-1611.	-32.22
	100000.	1671.	513.	397.	4205.	-3295.	-32.95

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OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	2.	0.	19.	63.45
	1000.	144.	42.	7.	0.	49.	49.14
	5000.	273.	81.	35.	0.	116.	23.22
	20000.	594.	179.	139.	0.	318.	15.89
	50000.	955.	293.	348.	0.	641.	12.82
	100000.	1671.	513.	696.	0.	1209.	12.09
0.0100$/1000 SCF	300.	58.	17.	2.	2.	17.	58.19
	1000.	144.	42.	7.	5.	44.	43.89
	5000.	273.	81.	35.	26.	90.	17.96
	20000.	594.	179.	139.	105.	213.	10.63
	50000.	955.	293.	348.	263.	378.	7.56
	100000.	1671.	513.	696.	526.	683.	6.83
0.0200$/1000 SCF	300.	58.	17.	2.	3.	16.	52.94
	1000.	144.	42.	7.	11.	39.	38.63
	5000.	273.	81.	35.	53.	64.	12.70
	20000.	594.	179.	139.	210.	108.	5.38
	50000.	955.	293.	348.	526.	115.	2.30
	100000.	1671.	513.	696.	1051.	158.	1.58
0.0400$/1000 SCF	300.	58.	17.	2.	6.	13.	42.43
	1000.	144.	42.	7.	21.	28.	28.12
	5000.	273.	81.	35.	105.	11.	2.19
	20000.	594.	179.	139.	420.	-103.	-5.13
	50000.	955.	293.	348.	1051.	-410.	-8.21
	100000.	1671.	513.	696.	2102.	-894.	-8.94
0.0800$/1000 SCF	300.	58.	17.	2.	13.	6.	21.40
	1000.	144.	42.	7.	42.	7.	7.09
	5000.	273.	81.	35.	210.	-94.	-18.83
	20000.	594.	179.	139.	841.	-523.	-26.16
	50000.	955.	293.	348.	2102.	-1462.	-29.23
	100000.	1671.	513.	696.	4205.	-2996.	-29.96

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	59.71
	1000.	144.	42.	3.	0.	45.	45.40
	5000.	273.	81.	16.	0.	97.	19.48
	20000.	594.	179.	64.	0.	243.	12.15
	50000.	955.	293.	161.	0.	454.	9.08
	100000.	1671.	513.	322.	0.	835.	8.35
0.0250$/1000 SCF							
	300.	58.	17.	1.	4.	14.	46.57
	1000.	144.	42.	3.	13.	32.	32.26
	5000.	273.	81.	16.	66.	32.	6.34
	20000.	594.	179.	64.	263.	-20.	-0.99
	50000.	955.	293.	161.	657.	-203.	-4.06
	100000.	1671.	513.	322.	1314.	-479.	-4.79
0.0500$/1000 SCF							
	300.	58.	17.	1.	8.	10.	33.43
	1000.	144.	42.	3.	26.	19.	19.12
	5000.	273.	81.	16.	131.	-34.	-6.80
	20000.	594.	179.	64.	526.	-283.	-14.13
	50000.	955.	293.	161.	1314.	-860.	-17.20
	100000.	1671.	513.	322.	2628.	-1793.	-17.93
0.1000$/1000 SCF							
	300.	58.	17.	1.	16.	2.	7.15
	1000.	144.	42.	3.	53.	-7.	-7.16
	5000.	273.	81.	16.	263.	-165.	-33.08
	20000.	594.	179.	64.	1051.	-808.	-40.41
	50000.	955.	293.	161.	2628.	-2174.	-43.48
	100000.	1671.	513.	322.	5256.	-4421.	-44.21
0.2000$/1000 SCF							
	300.	58.	17.	1.	32.	-14.	-45.41
	1000.	144.	42.	3.	105.	-60.	-59.72
	5000.	273.	81.	16.	526.	-428.	-85.64
	20000.	594.	179.	64.	2102.	-1859.	-92.97
	50000.	955.	293.	161.	5256.	-4802.	-96.04
	100000.	1671.	513.	322.	10512.	-9677.	-96.77

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OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	2.	0.	19.	61.95
	1000.	144.	42.	5.	0.	48.	47.65
	5000.	273.	81.	27.	0.	109.	21.72
	20000.	594.	179.	109.	0.	288.	14.40
	50000.	955.	293.	273.	0.	566.	11.32
	100000.	1671.	513.	547.	0.	1059.	10.59
0.0250$/1000 SCF							
	300.	58.	17.	2.	4.	15.	48.81
	1000.	144.	42.	5.	13.	35.	34.51
	5000.	273.	81.	27.	66.	43.	8.58
	20000.	594.	179.	109.	263.	25.	1.26
	50000.	955.	293.	273.	657.	-91.	-1.82
	100000.	1671.	513.	547.	1314.	-255.	-2.55
0.0500$/1000 SCF							
	300.	58.	17.	2.	8.	11.	35.67
	1000.	144.	42.	5.	26.	21.	21.37
	5000.	273.	81.	27.	131.	-23.	-4.56
	20000.	594.	179.	109.	526.	-238.	-11.88
	50000.	955.	293.	273.	1314.	-748.	-14.96
	100000.	1671.	513.	547.	2628.	-1569.	-15.69
0.1000$/1000 SCF							
	300.	58.	17.	2.	16.	3.	9.39
	1000.	144.	42.	5.	53.	-5.	-4.91
	5000.	273.	81.	27.	263.	-154.	-30.84
	20000.	594.	179.	109.	1051.	-763.	-38.16
	50000.	955.	293.	273.	2628.	-2062.	-41.24
	100000.	1671.	513.	547.	5256.	-4197.	-41.97
0.2000$/1000 SCF							
	300.	58.	17.	2.	32.	-13.	-43.17
	1000.	144.	42.	5.	105.	-57.	-57.47
	5000.	273.	81.	27.	526.	-417.	-83.40
	20000.	594.	179.	109.	2102.	-1814.	-90.72
	50000.	955.	293.	273.	5256.	-4690.	-93.80
	100000.	1671.	513.	547.	10512.	-9453.	-94.53

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	3.	0.	19.	64.94
	1000.	144.	42.	8.	0.	51.	50.64
	5000.	273.	81.	42.	0.	124.	24.71
	20000.	594.	179.	169.	0.	348.	17.39
	50000.	955.	293.	423.	0.	716.	14.31
	100000.	1671.	513.	846.	0.	1358.	13.58
0.0250$/1000 SCF							
	300.	58.	17.	3.	4.	16.	51.80
	1000.	144.	42.	8.	13.	37.	37.50
	5000.	273.	81.	42.	66.	58.	11.57
	20000.	594.	179.	169.	263.	85.	4.25
	50000.	955.	293.	423.	657.	59.	1.17
	100000.	1671.	513.	846.	1314.	44.	0.44
0.0500$/1000 SCF							
	300.	58.	17.	3.	8.	12.	38.66
	1000.	144.	42.	8.	26.	24.	24.36
	5000.	273.	81.	42.	131.	-8.	-1.57
	20000.	594.	179.	169.	526.	-178.	-8.89
	50000.	955.	293.	423.	1314.	-598.	-11.97
	100000.	1671.	513.	846.	2628.	-1270.	-12.70
0.1000$/1000 SCF							
	300.	58.	17.	3.	16.	4.	12.38
	1000.	144.	42.	8.	53.	-2.	-1.92
	5000.	273.	81.	42.	263.	-139.	-27.85
	20000.	594.	179.	169.	1051.	-703.	-35.17
	50000.	955.	293.	423.	2628.	-1912.	-38.25
	100000.	1671.	513.	846.	5256.	-3898.	-38.98
0.2000$/1000 SCF							
	300.	58.	17.	3.	32.	-12.	-40.18
	1000.	144.	42.	8.	105.	-54.	-54.48
	5000.	273.	81.	42.	526.	-402.	-80.41
	20000.	594.	179.	169.	2102.	-1755.	-87.73
	50000.	955.	293.	423.	5256.	-4540.	-90.81
	100000.	1671.	513.	846.	10512.	-9154.	-91.54

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT			NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
			FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)		
0.0000$/1000 SCF	300.	58.	17.	5.	0.	22.	72.42
	1000.	144.	42.	16.	0.	58.	58.11
	5000.	273.	81.	80.	0.	161.	32.19
	20000.	594.	179.	319.	0.	497.	24.86
	50000.	955.	293.	797.	0.	1089.	21.79
	100000.	1671.	513.	1593.	0.	2106.	21.06
0.0250$/1000 SCF	300.	58.	17.	5.	4.	18.	59.28
	1000.	144.	42.	16.	13.	45.	44.97
	5000.	273.	81.	80.	66.	95.	19.05
	20000.	594.	179.	319.	263.	234.	11.72
	50000.	955.	293.	797.	657.	432.	8.65
	100000.	1671.	513.	1593.	1314.	792.	7.92
0.0500$/1000 SCF	300.	58.	17.	5.	8.	14.	46.14
	1000.	144.	42.	16.	26.	32.	31.83
	5000.	273.	81.	80.	131.	30.	5.91
	20000.	594.	179.	319.	526.	-28.	-1.42
	50000.	955.	293.	797.	1314.	-225.	-4.49
	100000.	1671.	513.	1593.	2628.	-522.	-5.22
0.1000$/1000 SCF	300.	58.	17.	5.	16.	6.	19.86
	1000.	144.	42.	16.	53.	6.	5.55
	5000.	273.	81.	80.	263.	-102.	-20.37
	20000.	594.	179.	319.	1051.	-554.	-27.70
	50000.	955.	293.	797.	2628.	-1539.	-30.77
	100000.	1671.	513.	1593.	5256.	-3150.	-31.50
0.2000$/1000 SCF	300.	58.	17.	5.	32.	-10.	-32.70
	1000.	144.	42.	16.	105.	-47.	-47.01
	5000.	273.	81.	80.	526.	-365.	-72.93
	20000.	594.	179.	319.	2102.	-1605.	-80.26
	50000.	955.	293.	797.	5256.	-4167.	-83.33
	100000.	1671.	513.	1593.	10512.	-8406.	-84.06

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OFFGAS CARBON REQUIREMENT 6.96  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON         AT $2.50/MILLION BTU

   CREDIT         OFFGAS       CAPITAL             OPERATING COST-OR-CREDIT             NET              NET COST
                   FLOW         COST         FIXED       UTILITIES       RECOVERY     ANNUALIZED       OR SAVINGS(-)
                                             COST                         CREDIT    COST OR CREDIT(-)    PER SCFM
                   SCFM         (000)        (000)         (000)          (000)         (000)           $/SCFM
0.0000$/1000 SCF
                   300.          58.          17.            1.             0.            18.            60.59
                  1000.         144.          42.            4.             0.            46.            46.28
                  5000.         273.          81.           21.             0.           102.            20.36
                 20000.         594.         179.           82.             0.           261.            13.03
                 50000.         955.         293.          205.             0.           498.             9.96
                100000.        1671.         513.          410.             0.           923.             9.23
0.0348$/1000 SCF
                   300.          58.          17.            1.             5.            13.            42.30
                  1000.         144.          42.            4.            18.            28.            27.99
                  5000.         273.          81.           21.            91.            10.             2.07
                 20000.         594.         179.           82.           366.          -105.            -5.26
                 50000.         955.         293.          205.           915.          -417.            -8.33
                100000.        1671.         513.          410.          1829.          -906.            -9.06
0.0696$/1000 SCF
                   300.          58.          17.            1.            11.             7.            24.01
                  1000.         144.          42.            4.            37.            10.             9.70
                  5000.         273.          81.           21.           183.           -81.           -16.22
                 20000.         594.         179.           82.           732.          -471.           -23.55
                 50000.         955.         293.          205.          1829.         -1331.           -26.62
                100000.        1671.         513.          410.          3658.         -2735.           -27.35
0.1392$/1000 SCF
                   300.          58.          17.            1.            22.            -4.           -12.57
                  1000.         144.          42.            4.            73.           -27.           -26.88
                  5000.         273.          81.           21.           366.          -264.           -52.81
                 20000.         594.         179.           82.          1463.         -1203.           -60.13
                 50000.         955.         293.          205.          3658.         -3160.           -63.21
                100000.        1671.         513.          410.          7316.         -6394.           -63.94
0.2784$/1000 SCF
                   300.          58.          17.            1.            44.           -26.           -85.74
                  1000.         144.          42.            4.           146.          -100.          -100.04
                  5000.         273.          81.           21.           732.          -630.          -125.97
                 20000.         594.         179.           82.          2927.         -2666.          -133.30
                 50000.         955.         293.          205.          7316.         -6818.          -136.37
                100000.        1671.         513.          410.         14633.        -13710.          -137.10
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OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	2.	0.	19.	63.71
	1000.	144.	42.	7.	0.	49.	49.41
	5000.	273.	81.	36.	0.	117.	23.48
	20000.	594.	179.	144.	0.	323.	16.15
	50000.	955.	293.	361.	0.	654.	13.08
	100000.	1671.	513.	722.	0.	1235.	12.35
0.0348$/1000 SCF							
	300.	58.	17.	2.	5.	14.	45.42
	1000.	144.	42.	7.	18.	31.	31.12
	5000.	273.	81.	36.	91.	26.	5.19
	20000.	594.	179.	144.	366.	-43.	-2.14
	50000.	955.	293.	361.	915.	-261.	-5.21
	100000.	1671.	513.	722.	1829.	-594.	-5.94
0.0696$/1000 SCF							
	300.	58.	17.	2.	11.	8.	27.13
	1000.	144.	42.	7.	37.	13.	12.82
	5000.	273.	81.	36.	183.	-66.	-13.10
	20000.	594.	179.	144.	732.	-409.	-20.43
	50000.	955.	293.	361.	1829.	-1175.	-23.50
	100000.	1671.	513.	722.	3658.	-2423.	-24.23
0.1392$/1000 SCF							
	300.	58.	17.	2.	22.	-3.	-9.45
	1000.	144.	42.	7.	73.	-24.	-23.76
	5000.	273.	81.	36.	366.	-248.	-49.68
	20000.	594.	179.	144.	1463.	-1140.	-57.01
	50000.	955.	293.	361.	3658.	-3004.	-60.08
	100000.	1671.	513.	722.	7316.	-6081.	-60.81
0.2784$/1000 SCF							
	300.	58.	17.	2.	44.	-25.	-82.61
	1000.	144.	42.	7.	146.	-97.	-96.92
	5000.	273.	81.	36.	732.	-614.	-122.85
	20000.	594.	179.	144.	2927.	-2603.	-130.17
	50000.	955.	293.	361.	7316.	-6662.	-133.25
	100000.	1671.	513.	722.	14633.	-13398.	-133.98

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT			NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
			FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)		
0.0000$/1000 SCF							
	300.	58.	17.	3.	0.	20.	67.88
	1000.	144.	42.	11.	0.	54.	53.57
	5000.	273.	81.	57.	0.	138.	27.64
	20000.	594.	179.	228.	0.	406.	20.32
	50000.	955.	293.	569.	0.	862.	17.24
	100000.	1671.	513.	1139.	0.	1651.	16.51
0.0348$/1000 SCF							
	300.	58.	17.	3.	5.	15.	49.58
	1000.	144.	42.	11.	18.	35.	35.28
	5000.	273.	81.	57.	91.	47.	9.35
	20000.	594.	179.	228.	366.	41.	2.03
	50000.	955.	293.	569.	915.	-52.	-1.05
	100000.	1671.	513.	1139.	1829.	-178.	-1.78
0.0696$/1000 SCF							
	300.	58.	17.	3.	11.	9.	31.29
	1000.	144.	42.	11.	37.	17.	16.99
	5000.	273.	81.	57.	183.	-45.	-8.94
	20000.	594.	179.	228.	732.	-325.	-16.27
	50000.	955.	293.	569.	1829.	-967.	-19.34
	100000.	1671.	513.	1139.	3658.	-2007.	-20.07
0.1392$/1000 SCF							
	300.	58.	17.	3.	22.	-2.	-5.29
	1000.	144.	42.	11.	73.	-20.	-19.59
	5000.	273.	81.	57.	366.	-228.	-45.52
	20000.	594.	179.	228.	1463.	-1057.	-52.85
	50000.	955.	293.	569.	3658.	-2796.	-55.92
	100000.	1671.	513.	1139.	7316.	-5665.	-56.65
0.2784$/1000 SCF							
	300.	58.	17.	3.	44.	-24.	-78.45
	1000.	144.	42.	11.	146.	-93.	-92.76
	5000.	273.	81.	57.	732.	-593.	-118.68
	20000.	594.	179.	228.	2927.	-2520.	-126.01
	50000.	955.	293.	569.	7316.	-6454.	-129.08
	100000.	1671.	513.	1139.	14633.	-12981.	-129.81

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	7.	0.	23.	78.28
	1000.	144.	42.	22.	0.	64.	63.98
	5000.	273.	81.	109.	0.	190.	38.05
	20000.	594.	179.	436.	0.	614.	30.72
	50000.	955.	293.	1090.	0.	1383.	27.65
	100000.	1671.	513.	2180.	0.	2692.	26.92
0.0348$/1000 SCF	300.	58.	17.	7.	5.	18.	59.99
	1000.	144.	42.	22.	18.	46.	45.69
	5000.	273.	81.	109.	91.	99.	19.76
	20000.	594.	179.	436.	366.	249.	12.43
	50000.	955.	293.	1090.	915.	468.	9.36
	100000.	1671.	513.	2180.	1829.	863.	8.63
0.0696$/1000 SCF	300.	58.	17.	7.	11.	13.	41.70
	1000.	144.	42.	22.	37.	27.	27.39
	5000.	273.	81.	109.	183.	7.	1.47
	20000.	594.	179.	436.	732.	-117.	-5.86
	50000.	955.	293.	1090.	1829.	-447.	-8.93
	100000.	1671.	513.	2180.	3658.	-966.	-9.66
0.1392$/1000 SCF	300.	58.	17.	7.	22.	2.	5.12
	1000.	144.	42.	22.	73.	-9.	-9.19
	5000.	273.	81.	109.	366.	-176.	-35.11
	20000.	594.	179.	436.	1463.	-849.	-42.44
	50000.	955.	293.	1090.	3658.	-2276.	-45.51
	100000.	1671.	513.	2180.	7316.	-4624.	-46.24
0.2784$/1000 SCF	300.	58.	17.	7.	44.	-20.	-68.04
	1000.	144.	42.	22.	146.	-82.	-82.35
	5000.	273.	81.	109.	732.	-541.	-108.28
	20000.	594.	179.	436.	2927.	-2312.	-115.60
	50000.	955.	293.	1090.	7316.	-5934.	-118.68
	100000.	1671.	513.	2180.	14633.	-11941.	-119.41

OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	61.06
	1000.	144.	42.	5.	0.	47.	46.75
	5000.	273.	81.	23.	0.	104.	20.82
	20000.	594.	179.	91.	0.	270.	13.50
	50000.	955.	293.	228.	0.	521.	10.42
	100000.	1671.	513.	457.	0.	970.	9.70
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	12.	40.03
	1000.	144.	42.	5.	21.	26.	25.73
	5000.	273.	81.	23.	105.	-1.	-0.20
	20000.	594.	179.	91.	420.	-151.	-7.53
	50000.	955.	293.	228.	1051.	-530.	-10.60
	100000.	1671.	513.	457.	2102.	-1133.	-11.33
0.0800$/1000 SCF							
	300.	58.	17.	1.	13.	6.	19.01
	1000.	144.	42.	5.	42.	5.	4.70
	5000.	273.	81.	23.	210.	-106.	-21.22
	20000.	594.	179.	91.	841.	-571.	-28.55
	50000.	955.	293.	228.	2102.	-1581.	-31.62
	100000.	1671.	513.	457.	4205.	-3235.	-32.35
0.1600$/1000 SCF							
	300.	58.	17.	1.	25.	-7.	-23.04
	1000.	144.	42.	5.	84.	-37.	-37.35
	5000.	273.	81.	23.	420.	-316.	-63.27
	20000.	594.	179.	91.	1682.	-1412.	-70.60
	50000.	955.	293.	228.	4205.	-3684.	-73.67
	100000.	1671.	513.	457.	8410.	-7440.	-74.40
0.3200$/1000 SCF							
	300.	58.	17.	1.	50.	-32.	-107.14
	1000.	144.	42.	5.	168.	-121.	-121.44
	5000.	273.	81.	23.	841.	-737.	-147.37
	20000.	594.	179.	91.	3364.	-3094.	-154.69
	50000.	955.	293.	228.	8410.	-7888.	-157.77
	100000.	1671.	513.	457.	16819.	-15850.	-158.50

OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	2.	0.	19.	64.65
	1000.	144.	42.	8.	0.	50.	50.34
	5000.	273.	81.	41.	0.	122.	24.41
	20000.	594.	179.	163.	0.	342.	17.09
	50000.	955.	293.	408.	0.	701.	14.01
	100000.	1671.	513.	816.	0.	1328.	13.28
0.0400$/1000 SCF	300.	58.	17.	2.	6.	13.	43.62
	1000.	144.	42.	8.	21.	29.	29.32
	5000.	273.	81.	41.	105.	17.	3.39
	20000.	594.	179.	163.	420.	-79.	-3.94
	50000.	955.	293.	408.	1051.	-351.	-7.01
	100000.	1671.	513.	816.	2102.	-774.	-7.74
0.0800$/1000 SCF	300.	58.	17.	2.	13.	7.	22.60
	1000.	144.	42.	8.	42.	8.	8.29
	5000.	273.	81.	41.	210.	-88.	-17.63
	20000.	594.	179.	163.	841.	-499.	-24.96
	50000.	955.	293.	408.	2102.	-1402.	-28.04
	100000.	1671.	513.	816.	4205.	-2876.	-28.76
0.1600$/1000 SCF	300.	58.	17.	2.	25.	-6.	-19.45
	1000.	144.	42.	8.	84.	-34.	-33.76
	5000.	273.	81.	41.	420.	-298.	-59.68
	20000.	594.	179.	163.	1682.	-1340.	-67.01
	50000.	955.	293.	408.	4205.	-3504.	-70.08
	100000.	1671.	513.	816.	8410.	-7081.	-70.81
0.3200$/1000 SCF	300.	58.	17.	2.	50.	-31.	-103.55
	1000.	144.	42.	8.	168.	-118.	-117.85
	5000.	273.	81.	41.	841.	-719.	-143.78
	20000.	594.	179.	163.	3364.	-3022.	-151.11
	50000.	955.	293.	408.	8410.	-7709.	-154.18
	100000.	1671.	513.	816.	16819.	-15491.	-154.91

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     OFFGAS CARBON REQUIREMENT 8.00  LB CARBON/1000 SCF
     STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON        AT $2.50/MILLION BTU

  CREDIT          OFFGAS      CAPITAL          OPERATING COST-OR-CREDIT            NET           NET COST
                   FLOW        COST        FIXED      UTILITIES    RECOVERY     ANNUALIZED     OR SAVINGS(-)
                                            COST                    CREDIT   COST OR CREDIT(-)   PER SCFM
                   SCFM        (000)        (000)       (000)        (000)        (000)           $/SCFM

0.0000$/1000 SCF
                   300.         58.          17.          4.           0.          21.            69.43
                  1000.        144.          42.         13.           0.          55.            55.12
                  5000.        273.          81.         65.           0.         146.            29.20
                 20000.        594.         179.        259.           0.         437.            21.87
                 50000.        955.         293.        647.           0.         940.            18.80
                100000.       1671.         513.       1294.           0.        1807.            18.07
0.0400$/1000 SCF
                   300.         58.          17.          4.           6.          15.            48.41
                  1000.        144.          42.         13.          21.          34.            34.10
                  5000.        273.          81.         65.         105.          41.             8.17
                 20000.        594.         179.        259.         420.          17.             0.85
                 50000.        955.         293.        647.        1051.        -111.            -2.23
                100000.       1671.         513.       1294.        2102.        -296.            -2.96
0.0800$/1000 SCF
                   300.         58.          17.          4.          13.           8.            27.38
                  1000.        144.          42.         13.          42.          13.            13.08
                  5000.        273.          81.         65.         210.         -64.           -12.85
                 20000.        594.         179.        259.         841.        -404.           -20.18
                 50000.        955.         293.        647.        2102.       -1163.           -23.25
                100000.       1671.         513.       1294.        4205.       -2398.           -23.98
0.1600$/1000 SCF
                   300.         58.          17.          4.          25.          -4.           -14.67
                  1000.        144.          42.         13.          84.         -29.           -28.97
                  5000.        273.          81.         65.         420.        -274.           -54.90
                 20000.        594.         179.        259.        1682.       -1244.           -62.22
                 50000.        955.         293.        647.        4205.       -3265.           -65.30
                100000.       1671.         513.       1294.        8410.       -6603.           -66.03
0.3200$/1000 SCF
                   300.         58.          17.          4.          50.         -30.           -98.76
                  1000.        144.          42.         13.         168.        -113.          -113.07
                  5000.        273.          81.         65.         841.        -695.          -138.99
                 20000.        594.         179.        259.        3364.       -2926.          -146.32
                 50000.        955.         293.        647.        8410.       -7470.          -149.39
                100000.       1671.         513.       1294.       16819.      -15012.          -150.12
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OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	7.	0.	24.	81.39
	1000.	144.	42.	25.	0.	67.	67.09
	5000.	273.	81.	125.	0.	206.	41.16
	20000.	594.	179.	498.	0.	677.	33.83
	50000.	955.	293.	1245.	0.	1538.	30.76
	100000.	1671.	513.	2491.	0.	3003.	30.03
0.0400$/1000 SCF	300.	58.	17.	7.	6.	18.	60.37
	1000.	144.	42.	25.	21.	46.	46.06
	5000.	273.	81.	125.	105.	101.	20.14
	20000.	594.	179.	498.	420.	256.	12.81
	50000.	955.	293.	1245.	1051.	487.	9.74
	100000.	1671.	513.	2491.	2102.	901.	9.01
0.0800$/1000 SCF	300.	58.	17.	7.	13.	12.	39.35
	1000.	144.	42.	25.	42.	25.	25.04
	5000.	273.	81.	125.	210.	-4.	-0.89
	20000.	594.	179.	498.	841.	-164.	-8.21
	50000.	955.	293.	1245.	2102.	-564.	-11.29
	100000.	1671.	513.	2491.	4205.	-1202.	-12.02
0.1600$/1000 SCF	300.	58.	17.	7.	25.	-1.	-2.70
	1000.	144.	42.	25.	84.	-17.	-17.01
	5000.	273.	81.	125.	420.	-215.	-42.94
	20000.	594.	179.	498.	1682.	-1005.	-50.26
	50000.	955.	293.	1245.	4205.	-2667.	-53.34
	100000.	1671.	513.	2491.	8410.	-5406.	-54.06
0.3200$/1000 SCF	300.	58.	17.	7.	50.	-26.	-86.80
	1000.	144.	42.	25.	168.	-101.	-101.11
	5000.	273.	81.	125.	841.	-635.	-127.03
	20000.	594.	179.	498.	3364.	-2687.	-134.36
	50000.	955.	293.	1245.	8410.	-6872.	-137.43
	100000.	1671.	513.	2491.	16819.	-13816.	-138.16

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OFFGAS CARBON REQUIREMENT10.00  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON        AT $2.50/MILLION BTU

  CREDIT          OFFGAS       CAPITAL          OPERATING COST-OR-CREDIT                NET            NET COST
                   FLOW         COST        FIXED      UTILITIES       RECOVERY      ANNUALIZED      OR SAVINGS(-)
                                            COST                        CREDIT    COST OR CREDIT(-)    PER SCFM
                   SCFM         (000)       (000)        (000)          (000)          (000)           $/SCFM
0.0000$/1000 SCF
                   300.          58.         17.          2.             0.            19.             61.95
                  1000.         144.         42.          5.             0.            48.             47.65
                  5000.         273.         81.         27.             0.           109.             21.72
                 20000.         594.        179.        109.             0.           288.             14.40
                 50000.         955.        293.        273.             0.           566.             11.32
                100000.        1671.        513.        547.             0.          1059.             10.59
0.0500$/1000 SCF
                   300.          58.         17.          2.             8.            11.             35.67
                  1000.         144.         42.          5.            26.            21.             21.37
                  5000.         273.         81.         27.           131.           -23.             -4.56
                 20000.         594.        179.        109.           526.          -238.            -11.88
                 50000.         955.        293.        273.          1314.          -748.            -14.96
                100000.        1671.        513.        547.          2628.         -1569.            -15.69
0.1000$/1000 SCF
                   300.          58.         17.          2.            16.             3.              9.39
                  1000.         144.         42.          5.            53.            -5.             -4.91
                  5000.         273.         81.         27.           263.          -154.            -30.84
                 20000.         594.        179.        109.          1051.          -763.            -38.16
                 50000.         955.        293.        273.          2628.         -2062.            -41.24
                100000.        1671.        513.        547.          5256.         -4197.            -41.97
0.2000$/1000 SCF
                   300.          58.         17.          2.            32.           -13.            -43.17
                  1000.         144.         42.          5.           105.           -57.            -57.47
                  5000.         273.         81.         27.           526.          -417.            -83.40
                 20000.         594.        179.        109.          2102.         -1814.            -90.72
                 50000.         955.        293.        273.          5256.         -4690.            -93.80
                100000.        1671.        513.        547.         10512.         -9453.            -94.53
0.4000$/1000 SCF
                   300.          58.         17.          2.            63.           -44.           -148.29
                  1000.         144.         42.          5.           210.          -163.           -162.59
                  5000.         273.         81.         27.          1051.          -943.           -188.52
                 20000.         594.        179.        109.          4205.         -3917.           -195.84
                 50000.         955.        293.        273.         10512.         -9946.           -198.92
                100000.        1671.        513.        547.         21024.        -19965.           -199.65
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OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON   AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	3.	0.	20.	66.44
	1000.	144.	42.	10.	0.	52.	52.13
	5000.	273.	81.	50.	0.	131.	26.21
	20000.	594.	179.	199.	0.	378.	18.88
	50000.	955.	293.	498.	0.	790.	15.81
	100000.	1671.	513.	995.	0.	1508.	15.08
0.0500$/1000 SCF	300.	58.	17.	3.	8.	12.	40.16
	1000.	144.	42.	10.	26.	26.	25.85
	5000.	273.	81.	50.	131.	-0.	-0.07
	20000.	594.	179.	199.	526.	-148.	-7.40
	50000.	955.	293.	498.	1314.	-524.	-10.47
	100000.	1671.	513.	995.	2628.	-1120.	-11.20
0.1000$/1000 SCF	300.	58.	17.	3.	16.	4.	13.88
	1000.	144.	42.	10.	53.	-0.	-0.43
	5000.	273.	81.	50.	263.	-132.	-26.35
	20000.	594.	179.	199.	1051.	-674.	-33.68
	50000.	955.	293.	498.	2628.	-1838.	-36.75
	100000.	1671.	513.	995.	5256.	-3748.	-37.48
0.2000$/1000 SCF	300.	58.	17.	3.	32.	-12.	-38.68
	1000.	144.	42.	10.	105.	-53.	-52.99
	5000.	273.	81.	50.	526.	-395.	-78.91
	20000.	594.	179.	199.	2102.	-1725.	-86.24
	50000.	955.	293.	498.	5256.	-4466.	-89.31
	100000.	1671.	513.	995.	10512.	-9004.	-90.04
0.4000$/1000 SCF	300.	58.	17.	3.	63.	-43.	-143.80
	1000.	144.	42.	10.	210.	-158.	-158.11
	5000.	273.	81.	50.	1051.	-920.	-184.03
	20000.	594.	179.	199.	4205.	-3827.	-191.36
	50000.	955.	293.	498.	10512.	-9722.	-194.43
	100000.	1671.	513.	995.	21024.	-19516.	-195.16

OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $2.50/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	5.	0.	22.	72.42
	1000.	144.	42.	16.	0.	58.	58.11
	5000.	273.	81.	80.	0.	161.	32.19
	20000.	594.	179.	319.	0.	497.	24.86
	50000.	955.	293.	797.	0.	1089.	21.79
	100000.	1671.	513.	1593.	0.	2106.	21.06
0.0500$/1000 SCF							
	300.	58.	17.	5.	8.	14.	46.14
	1000.	144.	42.	16.	26.	32.	31.83
	5000.	273.	81.	80.	131.	30.	5.91
	20000.	594.	179.	319.	526.	-28.	-1.42
	50000.	955.	293.	797.	1314.	-225.	-4.49
	100000.	1671.	513.	1593.	2628.	-522.	-5.22
0.1000$/1000 SCF							
	300.	58.	17.	5.	16.	6.	19.86
	1000.	144.	42.	16.	53.	6.	5.55
	5000.	273.	81.	80.	263.	-102.	-20.37
	20000.	594.	179.	319.	1051.	-554.	-27.70
	50000.	955.	293.	797.	2628.	-1539.	-30.77
	100000.	1671.	513.	1593.	5256.	-3150.	-31.50
0.2000$/1000 SCF							
	300.	58.	17.	5.	32.	-10.	-32.70
	1000.	144.	42.	16.	105.	-47.	-47.01
	5000.	273.	81.	80.	526.	-365.	-72.93
	20000.	594.	179.	319.	2102.	-1605.	-80.26
	50000.	955.	293.	797.	5256.	-4167.	-83.33
	100000.	1671.	513.	1593.	10512.	-8406.	-84.06
0.4000$/1000 SCF							
	300.	58.	17.	5.	63.	-41.	-137.82
	1000.	144.	42.	16.	210.	-152.	-152.13
	5000.	273.	81.	80.	1051.	-890.	-178.05
	20000.	594.	179.	319.	4205.	-3708.	-185.38
	50000.	955.	293.	797.	10512.	-9423.	-188.45
	100000.	1671.	513.	1593.	21024.	-18918.	-189.18

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OFFGAS CARBON REQUIREMENT10.00  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON          AT $2.50/MILLION BTU

     CREDIT          OFFGAS        CAPITAL          OPERATING COST-OR-CREDIT                 NET              NET COST
                      FLOW          COST         FIXED      UTILITIES      RECOVERY      ANNUALIZED        OR SAVINGS(-)
                                                 COST                      CREDIT    COST OR CREDIT(-)      PER SCFM
                      SCFM          (000)        (000)        (000)        (000)          (000)             $/SCFM
  0.0000$/1000 SCF
                       300.           58.          17.           9.           0.            26.              87.37
                      1000.          144.          42.          31.           0.            73.              73.07
                      5000.          273.          81.         154.           0.           236.              47.14
                     20000.          594.         179.         618.           0.           796.              39.82
                     50000.          955.         293.        1544.           0.          1837.              36.74
                    100000.         1671.         513.        3089.           0.          3601.              36.01
  0.0500$/1000 SCF
                       300.           58.          17.           9.           8.            18.              61.09
                      1000.          144.          42.          31.          26.            47.              46.79
                      5000.          273.          81.         154.         131.           104.              20.86
                     20000.          594.         179.         618.         526.           271.              13.54
                     50000.          955.         293.        1544.        1314.           523.              10.46
                    100000.         1671.         513.        3089.        2628.           973.               9.73
  0.1000$/1000 SCF
                       300.           58.          17.           9.          16.            10.              34.81
                      1000.          144.          42.          31.          53.            21.              20.51
                      5000.          273.          81.         154.         263.           -27.              -5.42
                     20000.          594.         179.         618.        1051.          -255.             -12.74
                     50000.          955.         293.        1544.        2628.          -791.             -15.82
                    100000.         1671.         513.        3089.        5256.         -1655.             -16.55
  0.2000$/1000 SCF
                       300.           58.          17.           9.          32.            -5.             -17.75
                      1000.          144.          42.          31.         105.           -32.             -32.05
                      5000.          273.          81.         154.         526.          -290.             -57.98
                     20000.          594.         179.         618.        2102.         -1306.             -65.30
                     50000.          955.         293.        1544.        5256.         -3419.             -68.38
                    100000.         1671.         513.        3089.       10512.         -6911.             -69.11
  0.4000$/1000 SCF
                       300.           58.          17.           9.          63.           -37.            -122.87
                      1000.          144.          42.          31.         210.          -137.            -137.17
                      5000.          273.          81.         154.        1051.          -815.            -163.10
                     20000.          594.         179.         618.        4205.         -3408.            -170.42
                     50000.          955.         293.        1544.       10512.         -8675.            -173.50
                    100000.         1671.         513.        3089.       21024.        -17423.            -174.23
```

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.55
	1000.	144.	42.	1.	0.	43.	43.24
	5000.	273.	81.	5.	0.	87.	17.32
	20000.	594.	179.	21.	0.	200.	9.99
	50000.	955.	293.	53.	0.	346.	6.92
	100000.	1671.	513.	106.	0.	619.	6.19
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.29
	1000.	144.	42.	1.	0.	43.	42.98
	5000.	273.	81.	5.	1.	85.	17.06
	20000.	594.	179.	21.	5.	195.	9.73
	50000.	955.	293.	53.	13.	333.	6.66
	100000.	1671.	513.	106.	26.	593.	5.93
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.03
	1000.	144.	42.	1.	1.	43.	42.72
	5000.	273.	81.	5.	3.	84.	16.79
	20000.	594.	179.	21.	11.	189.	9.47
	50000.	955.	293.	53.	26.	320.	6.39
	100000.	1671.	513.	106.	53.	566.	5.66
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.50
	1000.	144.	42.	1.	1.	42.	42.19
	5000.	273.	81.	5.	5.	81.	16.27
	20000.	594.	179.	21.	21.	179.	8.94
	50000.	955.	293.	53.	53.	293.	5.87
	100000.	1671.	513.	106.	105.	514.	5.14
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.45
	1000.	144.	42.	1.	2.	41.	41.14
	5000.	273.	81.	5.	11.	76.	15.22
	20000.	594.	179.	21.	42.	158.	7.89
	50000.	955.	293.	53.	105.	241.	4.82
	100000.	1671.	513.	106.	210.	409.	4.09

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OFFGAS CARBON REQUIREMENT 0.10  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON          AT $5.00/MILLION BTU

  CREDIT          OFFGAS       CAPITAL              OPERATING COST-OR-CREDIT                NET               NET COST
                   FLOW         COST         FIXED        UTILITIES      RECOVERY        ANNUALIZED        OR SAVINGS(-)
                                             COST                         CREDIT     COST OR CREDIT(-)     PER SCFM
                   SCFM         (000)        (000)          (000)          (000)           (000)             $/SCFM
0.0000$/1000 SCF
                    300.          58.          17.            0.             0.             17.               57.63
                   1000.         144.          42.            1.             0.             43.               43.33
                   5000.         273.          81.            6.             0.             87.               17.40
                  20000.         594.         179.           23.             0.            202.               10.08
                  50000.         955.         293.           57.             0.            350.                7.00
                 100000.        1671.         513.          115.             0.            627.                6.27
0.0005$/1000 SCF
                    300.          58.          17.            0.             0.             17.               57.37
                   1000.         144.          42.            1.             0.             43.               43.06
                   5000.         273.          81.            6.             1.             86.               17.14
                  20000.         594.         179.           23.             5.            196.                9.81
                  50000.         955.         293.           57.            13.            337.                6.74
                 100000.        1671.         513.          115.            26.            601.                6.01
0.0010$/1000 SCF
                    300.          58.          17.            0.             0.             17.               57.11
                   1000.         144.          42.            1.             1.             43.               42.80
                   5000.         273.          81.            6.             3.             84.               16.88
                  20000.         594.         179.           23.            11.            191.                9.55
                  50000.         955.         293.           57.            26.            324.                6.48
                 100000.        1671.         513.          115.            53.            575.                5.75
0.0020$/1000 SCF
                    300.          58.          17.            0.             0.             17.               56.58
                   1000.         144.          42.            1.             1.             42.               42.28
                   5000.         273.          81.            6.             5.             82.               16.35
                  20000.         594.         179.           23.            21.            180.                9.02
                  50000.         955.         293.           57.            53.            298.                5.95
                 100000.        1671.         513.          115.           105.            522.                5.22
0.0040$/1000 SCF
                    300.          58.          17.            0.             1.             17.               55.53
                   1000.         144.          42.            1.             2.             41.               41.23
                   5000.         273.          81.            6.            11.             76.               15.30
                  20000.         594.         179.           23.            42.            159.                7.97
                  50000.         955.         293.           57.           105.            245.                4.90
                 100000.        1671.         513.          115.           210.            417.                4.17
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OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.75
	1000.	144.	42.	1.	0.	43.	43.44
	5000.	273.	81.	6.	0.	88.	17.51
	20000.	594.	179.	25.	0.	204.	10.19
	50000.	955.	293.	63.	0.	356.	7.11
	100000.	1671.	513.	126.	0.	638.	6.38
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.48
	1000.	144.	42.	1.	0.	43.	43.18
	5000.	273.	81.	6.	1.	86.	17.25
	20000.	594.	179.	25.	5.	198.	9.92
	50000.	955.	293.	63.	13.	342.	6.85
	100000.	1671.	513.	126.	26.	612.	6.12
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.22
	1000.	144.	42.	1.	1.	43.	42.91
	5000.	273.	81.	6.	3.	85.	16.99
	20000.	594.	179.	25.	11.	193.	9.66
	50000.	955.	293.	63.	26.	329.	6.59
	100000.	1671.	513.	126.	53.	586.	5.86
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.69
	1000.	144.	42.	1.	1.	42.	42.39
	5000.	273.	81.	6.	5.	82.	16.46
	20000.	594.	179.	25.	21.	183.	9.13
	50000.	955.	293.	63.	53.	303.	6.06
	100000.	1671.	513.	126.	105.	533.	5.33
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.64
	1000.	144.	42.	1.	2.	41.	41.34
	5000.	273.	81.	6.	11.	77.	15.41
	20000.	594.	179.	25.	42.	162.	8.08
	50000.	955.	293.	63.	105.	250.	5.01
	100000.	1671.	513.	126.	210.	428.	4.28

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	0.	0.	17.	58.02
	1000.	144.	42.	2.	0.	44.	43.72
	5000.	273.	81.	8.	0.	89.	17.79
	20000.	594.	179.	31.	0.	209.	10.46
	50000.	955.	293.	77.	0.	369.	7.39
	100000.	1671.	513.	153.	0.	666.	6.66
0.0005$/1000 SCF	300.	58.	17.	0.	0.	17.	57.76
	1000.	144.	42.	2.	0.	43.	43.45
	5000.	273.	81.	8.	1.	88.	17.53
	20000.	594.	179.	31.	5.	204.	10.20
	50000.	955.	293.	77.	13.	356.	7.13
	100000.	1671.	513.	153.	26.	640.	6.40
0.0010$/1000 SCF	300.	58.	17.	0.	0.	17.	57.50
	1000.	144.	42.	2.	1.	43.	43.19
	5000.	273.	81.	8.	3.	86.	17.26
	20000.	594.	179.	31.	11.	199.	9.94
	50000.	955.	293.	77.	26.	343.	6.86
	100000.	1671.	513.	153.	53.	613.	6.13
0.0020$/1000 SCF	300.	58.	17.	0.	0.	17.	56.97
	1000.	144.	42.	2.	1.	43.	42.66
	5000.	273.	81.	8.	5.	84.	16.74
	20000.	594.	179.	31.	21.	188.	9.41
	50000.	955.	293.	77.	53.	317.	6.34
	100000.	1671.	513.	153.	105.	561.	5.61
0.0040$/1000 SCF	300.	58.	17.	0.	1.	17.	55.92
	1000.	144.	42.	2.	2.	42.	41.61
	5000.	273.	81.	8.	11.	78.	15.69
	20000.	594.	179.	31.	42.	167.	8.36
	50000.	955.	293.	77.	105.	264.	5.29
	100000.	1671.	513.	153.	210.	456.	4.56

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OFFGAS CARBON REQUIREMENT 0.50  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON          AT $5.00/MILLION BTU

   CREDIT          OFFGAS        CAPITAL          OPERATING COST-OR-CREDIT                   NET              NET COST
                    FLOW          COST        FIXED        UTILITIES      RECOVERY       ANNUALIZED         OR SAVINGS(-)
                                              COST                         CREDIT     COST OR CREDIT(-)      PER SCFM
                    SCFM          (000)       (000)          (000)          (000)          (000)              $/SCFM
0.0000$/1000 SCF
                     300.           58.         17.            0.             0.            17.                57.88
                    1000.          144.         42.            1.             0.            44.                43.58
                    5000.          273.         81.            7.             0.            88.                17.65
                   20000.          594.        179.           28.             0.           206.                10.32
                   50000.          955.        293.           70.             0.           363.                 7.25
                  100000.         1671.        513.          140.             0.           652.                 6.52
0.0025$/1000 SCF
                     300.           58.         17.            0.             0.            17.                56.57
                    1000.          144.         42.            1.             1.            42.                42.26
                    5000.          273.         81.            7.             7.            82.                16.34
                   20000.          594.        179.           28.            26.           180.                 9.01
                   50000.          955.        293.           70.            66.           297.                 5.94
                  100000.         1671.        513.          140.           131.           521.                 5.21
0.0050$/1000 SCF
                     300.           58.         17.            0.             1.            17.                55.26
                    1000.          144.         42.            1.             3.            41.                40.95
                    5000.          273.         81.            7.            13.            75.                15.02
                   20000.          594.        179.           28.            53.           154.                 7.70
                   50000.          955.        293.           70.           131.           231.                 4.62
                  100000.         1671.        513.          140.           263.           389.                 3.89
0.0100$/1000 SCF
                     300.           58.         17.            0.             2.            16.                52.63
                    1000.          144.         42.            1.             5.            38.                38.32
                    5000.          273.         81.            7.            26.            62.                12.39
                   20000.          594.        179.           28.           105.           101.                 5.07
                   50000.          955.        293.           70.           263.           100.                 1.99
                  100000.         1671.        513.          140.           526.           127.                 1.27
0.0200$/1000 SCF
                     300.           58.         17.            0.             3.            14.                47.37
                    1000.          144.         42.            1.            11.            33.                33.06
                    5000.          273.         81.            7.            53.            36.                 7.14
                   20000.          594.        179.           28.           210.            -4.                -0.19
                   50000.          955.        293.           70.           526.          -163.                -3.26
                  100000.         1671.        513.          140.          1051.          -399.                -3.99
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OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	17.	58.30
	1000.	144.	42.	2.	0.	44.	43.99
	5000.	273.	81.	9.	0.	90.	18.07
	20000.	594.	179.	36.	0.	215.	10.74
	50000.	955.	293.	91.	0.	383.	7.67
	100000.	1671.	513.	181.	0.	694.	6.94
0.0025$/1000 SCF	300.	58.	17.	1.	0.	17.	56.99
	1000.	144.	42.	2.	1.	43.	42.68
	5000.	273.	81.	9.	7.	84.	16.75
	20000.	594.	179.	36.	26.	189.	9.43
	50000.	955.	293.	91.	66.	318.	6.35
	100000.	1671.	513.	181.	131.	562.	5.62
0.0050$/1000 SCF	300.	58.	17.	1.	1.	17.	55.67
	1000.	144.	42.	2.	3.	41.	41.36
	5000.	273.	81.	9.	13.	77.	15.44
	20000.	594.	179.	36.	53.	162.	8.11
	50000.	955.	293.	91.	131.	252.	5.04
	100000.	1671.	513.	181.	263.	431.	4.31
0.0100$/1000 SCF	300.	58.	17.	1.	2.	16.	53.04
	1000.	144.	42.	2.	5.	39.	38.74
	5000.	273.	81.	9.	26.	64.	12.81
	20000.	594.	179.	36.	105.	110.	5.48
	50000.	955.	293.	91.	263.	121.	2.41
	100000.	1671.	513.	181.	526.	168.	1.68
0.0200$/1000 SCF	300.	58.	17.	1.	3.	14.	47.79
	1000.	144.	42.	2.	11.	33.	33.48
	5000.	273.	81.	9.	53.	38.	7.55
	20000.	594.	179.	36.	210.	5.	0.23
	50000.	955.	293.	91.	526.	-142.	-2.85
	100000.	1671.	513.	181.	1051.	-357.	-3.57

OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	58.85
	1000.	144.	42.	2.	0.	45.	44.55
	5000.	273.	81.	12.	0.	93.	18.62
	20000.	594.	179.	47.	0.	226.	11.29
	50000.	955.	293.	118.	0.	411.	8.22
	100000.	1671.	513.	237.	0.	749.	7.49
0.0025$/1000 SCF							
	300.	58.	17.	1.	0.	17.	57.54
	1000.	144.	42.	2.	1.	43.	43.23
	5000.	273.	81.	12.	7.	87.	17.31
	20000.	594.	179.	47.	26.	200.	9.98
	50000.	955.	293.	118.	66.	345.	6.91
	100000.	1671.	513.	237.	131.	618.	6.18
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	56.23
	1000.	144.	42.	2.	3.	42.	41.92
	5000.	273.	81.	12.	13.	80.	15.99
	20000.	594.	179.	47.	53.	173.	8.67
	50000.	955.	293.	118.	131.	280.	5.59
	100000.	1671.	513.	237.	263.	486.	4.86
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.60
	1000.	144.	42.	2.	5.	39.	39.29
	5000.	273.	81.	12.	26.	67.	13.36
	20000.	594.	179.	47.	105.	121.	6.04
	50000.	955.	293.	118.	263.	148.	2.96
	100000.	1671.	513.	237.	526.	224.	2.24
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	15.	48.34
	1000.	144.	42.	2.	11.	34.	34.03
	5000.	273.	81.	12.	53.	41.	8.11
	20000.	594.	179.	47.	210.	16.	0.78
	50000.	955.	293.	118.	526.	-115.	-2.29
	100000.	1671.	513.	237.	1051.	-302.	-3.02

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OFFGAS CARBON REQUIREMENT 0.50  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON          AT $5.00/MILLION BTU

                                               OPERATING COST-OR-CREDIT                    NET                  NET COST
   CREDIT           OFFGAS        CAPITAL        FIXED      UTILITIES       RECOVERY    ANNUALIZED           OR SAVINGS(-)
                     FLOW          COST          COST                       CREDIT   COST OR CREDIT(-)         PER SCFM
                     SCFM          (000)         (000)        (000)          (000)         (000)                $/SCFM

 0.0000$/1000 SCF
                      300.           58.          17.           1.            0.            18.                  60.24
                     1000.          144.          42.           4.            0.            46.                  45.93
                     5000.          273.          81.          19.            0.           100.                  20.01
                    20000.          594.         179.          75.            0.           254.                  12.68
                    50000.          955.         293.         188.            0.           480.                   9.61
                   100000.         1671.         513.         375.            0.           888.                   8.88
 0.0025$/1000 SCF
                      300.           58.          17.           1.            0.            18.                  58.92
                     1000.          144.          42.           4.            1.            45.                  44.62
                     5000.          273.          81.          19.            7.            93.                  18.69
                    20000.          594.         179.          75.           26.           227.                  11.37
                    50000.          955.         293.         188.           66.           415.                   8.29
                   100000.         1671.         513.         375.          131.           756.                   7.56
 0.0050$/1000 SCF
                      300.           58.          17.           1.            1.            17.                  57.61
                     1000.          144.          42.           4.            3.            43.                  43.30
                     5000.          273.          81.          19.           13.            87.                  17.38
                    20000.          594.         179.          75.           53.           201.                  10.05
                    50000.          955.         293.         188.          131.           349.                   6.98
                   100000.         1671.         513.         375.          263.           625.                   6.25
 0.0100$/1000 SCF
                      300.           58.          17.           1.            2.            16.                  54.98
                     1000.          144.          42.           4.            5.            41.                  40.68
                     5000.          273.          81.          19.           26.            74.                  14.75
                    20000.          594.         179.          75.          105.           148.                   7.42
                    50000.          955.         293.         188.          263.           217.                   4.35
                   100000.         1671.         513.         375.          526.           362.                   3.62
 0.0200$/1000 SCF
                      300.           58.          17.           1.            3.            15.                  49.73
                     1000.          144.          42.           4.           11.            35.                  35.42
                     5000.          273.          81.          19.           53.            47.                   9.49
                    20000.          594.         179.          75.          210.            43.                   2.17
                    50000.          955.         293.         188.          526.           -45.                  -0.91
                   100000.         1671.         513.         375.         1051.          -164.                  -1.64
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OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	17.	58.30
	1000.	144.	42.	2.	0.	44.	43.99
	5000.	273.	81.	9.	0.	90.	18.07
	20000.	594.	179.	36.	0.	215.	10.74
	50000.	955.	293.	91.	0.	383.	7.67
	100000.	1671.	513.	181.	0.	694.	6.94
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	55.67
	1000.	144.	42.	2.	3.	41.	41.36
	5000.	273.	81.	9.	13.	77.	15.44
	20000.	594.	179.	36.	53.	162.	8.11
	50000.	955.	293.	91.	131.	252.	5.04
	100000.	1671.	513.	181.	263.	431.	4.31
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.04
	1000.	144.	42.	2.	5.	39.	38.74
	5000.	273.	81.	9.	26.	64.	12.81
	20000.	594.	179.	36.	105.	110.	5.48
	50000.	955.	293.	91.	263.	121.	2.41
	100000.	1671.	513.	181.	526.	168.	1.68
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	14.	47.79
	1000.	144.	42.	2.	11.	33.	33.48
	5000.	273.	81.	9.	53.	38.	7.55
	20000.	594.	179.	36.	210.	5.	0.23
	50000.	955.	293.	91.	526.	-142.	-2.85
	100000.	1671.	513.	181.	1051.	-357.	-3.57
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	11.	37.28
	1000.	144.	42.	2.	21.	23.	22.97
	5000.	273.	81.	9.	105.	-15.	-2.96
	20000.	594.	179.	36.	420.	-206.	-10.28
	50000.	955.	293.	91.	1051.	-668.	-13.36
	100000.	1671.	513.	181.	2102.	-1409.	-14.09

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT			NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
			FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)		
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	59.13
	1000.	144.	42.	3.	0.	45.	44.82
	5000.	273.	81.	13.	0.	94.	18.90
	20000.	594.	179.	53.	0.	231.	11.57
	50000.	955.	293.	132.	0.	425.	8.50
	100000.	1671.	513.	264.	0.	777.	7.77
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	56.50
	1000.	144.	42.	3.	3.	42.	42.20
	5000.	273.	81.	13.	13.	81.	16.27
	20000.	594.	179.	53.	53.	179.	8.94
	50000.	955.	293.	132.	131.	293.	5.87
	100000.	1671.	513.	264.	263.	514.	5.14
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.87
	1000.	144.	42.	3.	5.	40.	39.57
	5000.	273.	81.	13.	26.	68.	13.64
	20000.	594.	179.	53.	105.	126.	6.32
	50000.	955.	293.	132.	263.	162.	3.24
	100000.	1671.	513.	264.	526.	251.	2.51
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	15.	48.62
	1000.	144.	42.	3.	11.	34.	34.31
	5000.	273.	81.	13.	53.	42.	8.39
	20000.	594.	179.	53.	210.	21.	1.06
	50000.	955.	293.	132.	526.	-101.	-2.01
	100000.	1671.	513.	264.	1051.	-274.	-2.74
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	11.	38.11
	1000.	144.	42.	3.	21.	24.	23.80
	5000.	273.	81.	13.	105.	-11.	-2.13
	20000.	594.	179.	53.	420.	-189.	-9.45
	50000.	955.	293.	132.	1051.	-626.	-12.53
	100000.	1671.	513.	264.	2102.	-1326.	-13.26

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	60.24
	1000.	144.	42.	4.	0.	46.	45.93
	5000.	273.	81.	19.	0.	100.	20.01
	20000.	594.	179.	75.	0.	254.	12.68
	50000.	955.	293.	188.	0.	480.	9.61
	100000.	1671.	513.	375.	0.	888.	8.88
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	57.61
	1000.	144.	42.	4.	3.	43.	43.30
	5000.	273.	81.	19.	13.	87.	17.38
	20000.	594.	179.	75.	53.	201.	10.05
	50000.	955.	293.	188.	131.	349.	6.98
	100000.	1671.	513.	375.	263.	625.	6.25
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	54.98
	1000.	144.	42.	4.	5.	41.	40.68
	5000.	273.	81.	19.	26.	74.	14.75
	20000.	594.	179.	75.	105.	148.	7.42
	50000.	955.	293.	188.	263.	217.	4.35
	100000.	1671.	513.	375.	526.	362.	3.62
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	15.	49.73
	1000.	144.	42.	4.	11.	35.	35.42
	5000.	273.	81.	19.	53.	47.	9.49
	20000.	594.	179.	75.	210.	43.	2.17
	50000.	955.	293.	188.	526.	-45.	-0.91
	100000.	1671.	513.	375.	1051.	-164.	-1.64
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	12.	39.21
	1000.	144.	42.	4.	21.	25.	24.91
	5000.	273.	81.	19.	105.	-5.	-1.02
	20000.	594.	179.	75.	420.	-167.	-8.34
	50000.	955.	293.	188.	1051.	-571.	-11.42
	100000.	1671.	513.	375.	2102.	-1215.	-12.15

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW	CAPITAL COST	OPERATING COST-OR-CREDIT			NET	NET COST
			FIXED COST	UTILITIES	RECOVERY CREDIT	ANNUALIZED COST OR CREDIT(-)	OR SAVINGS(-) PER SCFM
	SCFM	(000)	(000)	(000)	(000)	(000)	$/SCFM
0.0000$/1000 SCF	300.	58.	17.	2.	0.	19.	63.01
	1000.	144.	42.	7.	0.	49.	48.70
	5000.	273.	81.	33.	0.	114.	22.78
	20000.	594.	179.	130.	0.	309.	15.45
	50000.	955.	293.	326.	0.	619.	12.37
	100000.	1671.	513.	652.	0.	1165.	11.65
0.0050$/1000 SCF	300.	58.	17.	2.	1.	18.	60.38
	1000.	144.	42.	7.	3.	46.	46.07
	5000.	273.	81.	33.	13.	101.	20.15
	20000.	594.	179.	130.	53.	256.	12.82
	50000.	955.	293.	326.	131.	487.	9.75
	100000.	1671.	513.	652.	263.	902.	9.02
0.0100$/1000 SCF	300.	58.	17.	2.	2.	17.	57.75
	1000.	144.	42.	7.	5.	43.	43.45
	5000.	273.	81.	33.	26.	88.	17.52
	20000.	594.	179.	130.	105.	204.	10.19
	50000.	955.	293.	326.	263.	356.	7.12
	100000.	1671.	513.	652.	526.	639.	6.39
0.0200$/1000 SCF	300.	58.	17.	2.	3.	16.	52.50
	1000.	144.	42.	7.	11.	38.	38.19
	5000.	273.	81.	33.	53.	61.	12.26
	20000.	594.	179.	130.	210.	99.	4.94
	50000.	955.	293.	326.	526.	93.	1.86
	100000.	1671.	513.	652.	1051.	113.	1.13
0.0400$/1000 SCF	300.	58.	17.	2.	6.	13.	41.98
	1000.	144.	42.	7.	21.	28.	27.68
	5000.	273.	81.	33.	105.	9.	1.75
	20000.	594.	179.	130.	420.	-112.	-5.58
	50000.	955.	293.	326.	1051.	-432.	-8.65
	100000.	1671.	513.	652.	2102.	-938.	-9.38

OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	58.63
	1000.	144.	42.	2.	0.	44.	44.32
	5000.	273.	81.	11.	0.	92.	18.39
	20000.	594.	179.	43.	0.	221.	11.07
	50000.	955.	293.	107.	0.	400.	7.99
	100000.	1671.	513.	214.	0.	726.	7.26
0.0070$/1000 SCF	300.	58.	17.	1.	1.	16.	54.96
	1000.	144.	42.	2.	4.	41.	40.66
	5000.	273.	81.	11.	18.	74.	14.73
	20000.	594.	179.	43.	73.	148.	7.41
	50000.	955.	293.	107.	183.	217.	4.33
	100000.	1671.	513.	214.	366.	360.	3.60
0.0139$/1000 SCF	300.	58.	17.	1.	2.	15.	51.30
	1000.	144.	42.	2.	7.	37.	37.00
	5000.	273.	81.	11.	37.	55.	11.07
	20000.	594.	179.	43.	146.	75.	3.75
	50000.	955.	293.	107.	366.	34.	0.67
	100000.	1671.	513.	214.	732.	-6.	-0.06
0.0279$/1000 SCF	300.	58.	17.	1.	4.	13.	43.98
	1000.	144.	42.	2.	15.	30.	29.68
	5000.	273.	81.	11.	73.	19.	3.75
	20000.	594.	179.	43.	293.	-72.	-3.58
	50000.	955.	293.	107.	732.	-333.	-6.65
	100000.	1671.	513.	214.	1464.	-738.	-7.38
0.0557$/1000 SCF	300.	58.	17.	1.	9.	9.	29.34
	1000.	144.	42.	2.	29.	15.	15.03
	5000.	273.	81.	11.	146.	-54.	-10.89
	20000.	594.	179.	43.	586.	-364.	-18.22
	50000.	955.	293.	107.	1464.	-1065.	-21.29
	100000.	1671.	513.	214.	2929.	-2202.	-22.02

OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT			NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
			FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)		
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	59.78
	1000.	144.	42.	3.	0.	45.	45.48
	5000.	273.	81.	16.	0.	98.	19.55
	20000.	594.	179.	66.	0.	244.	12.22
	50000.	955.	293.	165.	0.	458.	9.15
	100000.	1671.	513.	330.	0.	842.	8.42
0.0070$/1000 SCF	300.	58.	17.	1.	1.	17.	56.12
	1000.	144.	42.	3.	4.	42.	41.82
	5000.	273.	81.	16.	18.	79.	15.89
	20000.	594.	179.	66.	73.	171.	8.56
	50000.	955.	293.	165.	183.	274.	5.49
	100000.	1671.	513.	330.	366.	476.	4.76
0.0139$/1000 SCF	300.	58.	17.	1.	2.	16.	52.46
	1000.	144.	42.	3.	7.	38.	38.15
	5000.	273.	81.	16.	37.	61.	12.23
	20000.	594.	179.	66.	146.	98.	4.90
	50000.	955.	293.	165.	366.	91.	1.83
	100000.	1671.	513.	330.	732.	110.	1.10
0.0279$/1000 SCF	300.	58.	17.	1.	4.	14.	45.14
	1000.	144.	42.	3.	15.	31.	30.83
	5000.	273.	81.	16.	73.	25.	4.91
	20000.	594.	179.	66.	293.	-48.	-2.42
	50000.	955.	293.	165.	732.	-275.	-5.49
	100000.	1671.	513.	330.	1464.	-622.	-6.22
0.0557$/1000 SCF	300.	58.	17.	1.	9.	9.	30.50
	1000.	144.	42.	3.	29.	16.	16.19
	5000.	273.	81.	16.	146.	-49.	-9.74
	20000.	594.	179.	66.	586.	-341.	-17.06
	50000.	955.	293.	165.	1464.	-1007.	-20.14
	100000.	1671.	513.	330.	2929.	-2087.	-20.87

OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW	CAPITAL COST	OPERATING COST-OR-CREDIT			NET	NET COST
			FIXED COST	UTILITIES	RECOVERY CREDIT	ANNUALIZED COST OR CREDIT(-)	OR SAVINGS(-) PER SCFM
	SCFM	(000)	(000)	(000)	(000)	(000)	$/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	61.33
	1000.	144.	42.	5.	0.	47.	47.02
	5000.	273.	81.	24.	0.	105.	21.09
	20000.	594.	179.	97.	0.	275.	13.77
	50000.	955.	293.	242.	0.	535.	10.69
	100000.	1671.	513.	484.	0.	996.	9.96
0.0070$/1000 SCF	300.	58.	17.	1.	1.	17.	57.67
	1000.	144.	42.	5.	4.	43.	43.36
	5000.	273.	81.	24.	18.	87.	17.43
	20000.	594.	179.	97.	73.	202.	10.11
	50000.	955.	293.	242.	183.	352.	7.03
	100000.	1671.	513.	484.	366.	630.	6.30
0.0139$/1000 SCF	300.	58.	17.	1.	2.	16.	54.00
	1000.	144.	42.	5.	7.	40.	39.70
	5000.	273.	81.	24.	37.	69.	13.77
	20000.	594.	179.	97.	146.	129.	6.45
	50000.	955.	293.	242.	366.	169.	3.37
	100000.	1671.	513.	484.	732.	264.	2.64
0.0279$/1000 SCF	300.	58.	17.	1.	4.	14.	46.68
	1000.	144.	42.	5.	15.	32.	32.38
	5000.	273.	81.	24.	73.	32.	6.45
	20000.	594.	179.	97.	293.	-18.	-0.88
	50000.	955.	293.	242.	732.	-197.	-3.95
	100000.	1671.	513.	484.	1464.	-468.	-4.68
0.0557$/1000 SCF	300.	58.	17.	1.	9.	10.	32.04
	1000.	144.	42.	5.	29.	18.	17.73
	5000.	273.	81.	24.	146.	-41.	-8.19
	20000.	594.	179.	97.	586.	-310.	-15.52
	50000.	955.	293.	242.	1464.	-930.	-18.59
	100000.	1671.	513.	484.	2929.	-1932.	-19.32

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OFFGAS CARBON REQUIREMENT 1.39  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON          AT $5.00/MILLION BTU

                                                   OPERATING COST-OR-CREDIT                NET                 NET COST
   CREDIT           OFFGAS       CAPITAL                          UTILITIES      RECOVERY     ANNUALIZED          OR SAVINGS(-)
                     FLOW          COST         FIXED                              CREDIT   COST OR CREDIT(-)        PER SCFM
                                                 COST                              (000)         (000)               $/SCFM
                     SCFM          (000)        (000)             (000)

0.0000$/1000 SCF
                     300.            58.          17.               3.              0.            20.               65.19
                    1000.           144.          42.               9.              0.            51.               50.88
                    5000.           273.          81.              43.              0.           125.               24.95
                   20000.           594.         179.             174.              0.           353.               17.63
                   50000.           955.         293.             435.              0.           728.               14.55
                  100000.          1671.         513.             870.              0.          1382.               13.82
0.0070$/1000 SCF
                     300.            58.          17.               3.              1.            18.               61.52
                    1000.           144.          42.               9.              4.            47.               47.22
                    5000.           273.          81.              43.             18.           106.               21.29
                   20000.           594.         179.             174.             73.           279.               13.97
                   50000.           955.         293.             435.            183.           545.               10.89
                  100000.          1671.         513.             870.            366.          1016.               10.16
0.0139$/1000 SCF
                     300.            58.          17.               3.              2.            17.               57.86
                    1000.           144.          42.               9.              7.            44.               43.56
                    5000.           273.          81.              43.             37.            88.               17.63
                   20000.           594.         179.             174.            146.           206.               10.30
                   50000.           955.         293.             435.            366.           362.                7.23
                  100000.          1671.         513.             870.            732.           650.                6.50
0.0279$/1000 SCF
                     300.            58.          17.               3.              4.            15.               50.54
                    1000.           144.          42.               9.             15.            36.               36.24
                    5000.           273.          81.              43.             73.            52.               10.31
                   20000.           594.         179.             174.            293.            60.                2.98
                   50000.           955.         293.             435.            732.            -5.               -0.09
                  100000.          1671.         513.             870.           1464.           -82.               -0.82
0.0557$/1000 SCF
                     300.            58.          17.               3.              9.            11.               35.90
                    1000.           144.          42.               9.             29.            22.               21.59
                    5000.           273.          81.              43.            146.           -22.               -4.33
                   20000.           594.         179.             174.            586.          -233.              -11.66
                   50000.           955.         293.             435.           1464.          -737.              -14.73
                  100000.          1671.         513.             870.           2929.         -1546.              -15.46
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OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	59.13
	1000.	144.	42.	3.	0.	45.	44.82
	5000.	273.	81.	13.	0.	94.	18.90
	20000.	594.	179.	53.	0.	231.	11.57
	50000.	955.	293.	132.	0.	425.	8.50
	100000.	1671.	513.	264.	0.	777.	7.77
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.87
	1000.	144.	42.	3.	5.	40.	39.57
	5000.	273.	81.	13.	26.	68.	13.64
	20000.	594.	179.	53.	105.	126.	6.32
	50000.	955.	293.	132.	263.	162.	3.24
	100000.	1671.	513.	264.	526.	251.	2.51
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	15.	48.62
	1000.	144.	42.	3.	11.	34.	34.31
	5000.	273.	81.	13.	53.	42.	8.39
	20000.	594.	179.	53.	210.	21.	1.06
	50000.	955.	293.	132.	526.	-101.	-2.01
	100000.	1671.	513.	264.	1051.	-274.	-2.74
0.0400$/1000 SCF							
	300.	58.	17.	1.	6.	11.	38.11
	1000.	144.	42.	3.	21.	24.	23.80
	5000.	273.	81.	13.	105.	-11.	-2.13
	20000.	594.	179.	53.	420.	-189.	-9.45
	50000.	955.	293.	132.	1051.	-626.	-12.53
	100000.	1671.	513.	264.	2102.	-1326.	-13.26
0.0800$/1000 SCF							
	300.	58.	17.	1.	13.	5.	17.08
	1000.	144.	42.	3.	42.	3.	2.78
	5000.	273.	81.	13.	210.	-116.	-23.15
	20000.	594.	179.	53.	841.	-610.	-30.48
	50000.	955.	293.	132.	2102.	-1678.	-33.55
	100000.	1671.	513.	264.	4205.	-3428.	-34.28

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OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	60.79
	1000.	144.	42.	4.	0.	46.	46.49
	5000.	273.	81.	22.	0.	103.	20.56
	20000.	594.	179.	86.	0.	265.	13.23
	50000.	955.	293.	215.	0.	508.	10.16
	100000.	1671.	513.	430.	0.	943.	9.43
0.0100$/1000 SCF	300.	58.	17.	1.	2.	17.	55.54
	1000.	144.	42.	4.	5.	41.	41.23
	5000.	273.	81.	22.	26.	77.	15.30
	20000.	594.	179.	86.	105.	160.	7.98
	50000.	955.	293.	215.	263.	245.	4.90
	100000.	1671.	513.	430.	526.	417.	4.17
0.0200$/1000 SCF	300.	58.	17.	1.	3.	15.	50.28
	1000.	144.	42.	4.	11.	36.	35.97
	5000.	273.	81.	22.	53.	50.	10.05
	20000.	594.	179.	86.	210.	54.	2.72
	50000.	955.	293.	215.	526.	-18.	-0.35
	100000.	1671.	513.	430.	1051.	-108.	-1.08
0.0400$/1000 SCF	300.	58.	17.	1.	6.	12.	39.77
	1000.	144.	42.	4.	21.	25.	25.46
	5000.	273.	81.	22.	105.	-2.	-0.46
	20000.	594.	179.	86.	420.	-156.	-7.79
	50000.	955.	293.	215.	1051.	-543.	-10.86
	100000.	1671.	513.	430.	2102.	-1159.	-11.59
0.0800$/1000 SCF	300.	58.	17.	1.	13.	6.	18.74
	1000.	144.	42.	4.	42.	4.	4.44
	5000.	273.	81.	22.	210.	-107.	-21.49
	20000.	594.	179.	86.	841.	-576.	-28.81
	50000.	955.	293.	215.	2102.	-1594.	-31.89
	100000.	1671.	513.	430.	4205.	-3262.	-32.62

OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	2.	0.	19.	63.01
	1000.	144.	42.	7.	0.	49.	48.70
	5000.	273.	81.	33.	0.	114.	22.78
	20000.	594.	179.	130.	0.	309.	15.45
	50000.	955.	293.	326.	0.	619.	12.37
	100000.	1671.	513.	652.	0.	1165.	11.65
0.0100$/1000 SCF	300.	58.	17.	2.	2.	17.	57.75
	1000.	144.	42.	7.	5.	43.	43.45
	5000.	273.	81.	33.	26.	88.	17.52
	20000.	594.	179.	130.	105.	204.	10.19
	50000.	955.	293.	326.	263.	356.	7.12
	100000.	1671.	513.	652.	526.	639.	6.39
0.0200$/1000 SCF	300.	58.	17.	2.	3.	16.	52.50
	1000.	144.	42.	7.	11.	38.	38.19
	5000.	273.	81.	33.	53.	61.	12.26
	20000.	594.	179.	130.	210.	99.	4.94
	50000.	955.	293.	326.	526.	93.	1.86
	100000.	1671.	513.	652.	1051.	113.	1.13
0.0400$/1000 SCF	300.	58.	17.	2.	6.	13.	41.98
	1000.	144.	42.	7.	21.	28.	27.68
	5000.	273.	81.	33.	105.	9.	1.75
	20000.	594.	179.	130.	420.	-112.	-5.58
	50000.	955.	293.	326.	1051.	-432.	-8.65
	100000.	1671.	513.	652.	2102.	-938.	-9.38
0.0800$/1000 SCF	300.	58.	17.	2.	13.	6.	20.96
	1000.	144.	42.	7.	42.	7.	6.65
	5000.	273.	81.	33.	210.	-96.	-19.27
	20000.	594.	179.	130.	841.	-532.	-26.60
	50000.	955.	293.	326.	2102.	-1484.	-29.67
	100000.	1671.	513.	652.	4205.	-3040.	-30.40

OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	4.	0.	21.	68.55
	1000.	144.	42.	12.	0.	54.	54.24
	5000.	273.	81.	60.	0.	142.	28.32
	20000.	594.	179.	241.	0.	420.	20.99
	50000.	955.	293.	603.	0.	896.	17.91
	100000.	1671.	513.	1206.	0.	1719.	17.19
0.0100$/1000 SCF	300.	58.	17.	4.	2.	19.	63.29
	1000.	144.	42.	12.	5.	49.	48.99
	5000.	273.	81.	60.	26.	115.	23.06
	20000.	594.	179.	241.	105.	315.	15.73
	50000.	955.	293.	603.	263.	633.	12.66
	100000.	1671.	513.	1206.	526.	1193.	11.93
0.0200$/1000 SCF	300.	58.	17.	4.	3.	17.	58.04
	1000.	144.	42.	12.	11.	44.	43.73
	5000.	273.	81.	60.	53.	89.	17.80
	20000.	594.	179.	241.	210.	210.	10.48
	50000.	955.	293.	603.	526.	370.	7.40
	100000.	1671.	513.	1206.	1051.	667.	6.67
0.0400$/1000 SCF	300.	58.	17.	4.	6.	14.	47.52
	1000.	144.	42.	12.	21.	33.	33.22
	5000.	273.	81.	60.	105.	36.	7.29
	20000.	594.	179.	241.	420.	-1.	-0.04
	50000.	955.	293.	603.	1051.	-155.	-3.11
	100000.	1671.	513.	1206.	2102.	-384.	-3.84
0.0800$/1000 SCF	300.	58.	17.	4.	13.	8.	26.50
	1000.	144.	42.	12.	42.	12.	12.19
	5000.	273.	81.	60.	210.	-69.	-13.73
	20000.	594.	179.	241.	841.	-421.	-21.06
	50000.	955.	293.	603.	2102.	-1207.	-24.13
	100000.	1671.	513.	1206.	4205.	-2486.	-24.86

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	2.	0.	18.	61.62
	1000.	144.	42.	5.	0.	47.	47.32
	5000.	273.	81.	26.	0.	107.	21.39
	20000.	594.	179.	103.	0.	281.	14.06
	50000.	955.	293.	257.	0.	550.	10.99
	100000.	1671.	513.	514.	0.	1026.	10.26
0.0250$/1000 SCF							
	300.	58.	17.	2.	4.	15.	48.48
	1000.	144.	42.	5.	13.	34.	34.18
	5000.	273.	81.	26.	66.	41.	8.25
	20000.	594.	179.	103.	263.	18.	0.92
	50000.	955.	293.	257.	657.	-107.	-2.15
	100000.	1671.	513.	514.	1314.	-288.	-2.88
0.0500$/1000 SCF							
	300.	58.	17.	2.	8.	11.	35.34
	1000.	144.	42.	5.	26.	21.	21.04
	5000.	273.	81.	26.	131.	-24.	-4.89
	20000.	594.	179.	103.	526.	-244.	-12.22
	50000.	955.	293.	257.	1314.	-764.	-15.29
	100000.	1671.	513.	514.	2628.	-1602.	-16.02
0.1000$/1000 SCF							
	300.	58.	17.	2.	16.	3.	9.06
	1000.	144.	42.	5.	53.	-5.	-5.24
	5000.	273.	81.	26.	263.	-156.	-31.17
	20000.	594.	179.	103.	1051.	-770.	-38.50
	50000.	955.	293.	257.	2628.	-2078.	-41.57
	100000.	1671.	513.	514.	5256.	-4230.	-42.30
0.2000$/1000 SCF							
	300.	58.	17.	2.	32.	-13.	-43.50
	1000.	144.	42.	5.	105.	-58.	-57.80
	5000.	273.	81.	26.	526.	-419.	-83.73
	20000.	594.	179.	103.	2102.	-1821.	-91.06
	50000.	955.	293.	257.	5256.	-4706.	-94.13
	100000.	1671.	513.	514.	10512.	-9486.	-94.86

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	3.	0.	20.	65.78
	1000.	144.	42.	9.	0.	51.	51.47
	5000.	273.	81.	46.	0.	128.	25.55
	20000.	594.	179.	186.	0.	364.	18.22
	50000.	955.	293.	464.	0.	757.	15.14
	100000.	1671.	513.	929.	0.	1442.	14.42
0.0250$/1000 SCF	300.	58.	17.	3.	4.	16.	52.64
	1000.	144.	42.	9.	13.	38.	38.33
	5000.	273.	81.	46.	66.	62.	12.41
	20000.	594.	179.	186.	263.	102.	5.08
	50000.	955.	293.	464.	657.	100.	2.00
	100000.	1671.	513.	929.	1314.	128.	1.28
0.0500$/1000 SCF	300.	58.	17.	3.	8.	12.	39.50
	1000.	144.	42.	9.	26.	25.	25.19
	5000.	273.	81.	46.	131.	-4.	-0.73
	20000.	594.	179.	186.	526.	-161.	-8.06
	50000.	955.	293.	464.	1314.	-557.	-11.14
	100000.	1671.	513.	929.	2628.	-1186.	-11.86
0.1000$/1000 SCF	300.	58.	17.	3.	16.	4.	13.22
	1000.	144.	42.	9.	53.	-1.	-1.09
	5000.	273.	81.	46.	263.	-135.	-27.01
	20000.	594.	179.	186.	1051.	-687.	-34.34
	50000.	955.	293.	464.	2628.	-1871.	-37.42
	100000.	1671.	513.	929.	5256.	-3814.	-38.14
0.2000$/1000 SCF	300.	58.	17.	3.	32.	-12.	-39.34
	1000.	144.	42.	9.	105.	-54.	-53.65
	5000.	273.	81.	46.	526.	-398.	-79.57
	20000.	594.	179.	186.	2102.	-1738.	-86.90
	50000.	955.	293.	464.	5256.	-4499.	-89.98
	100000.	1671.	513.	929.	10512.	-9070.	-90.70

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OFFGAS CARBON REQUIREMENT 5.00  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON          AT $5.00/MILLION BTU

    CREDIT        OFFGAS       CAPITAL            OPERATING COST-OR-CREDIT               NET              NET COST
                   FLOW         COST        FIXED       UTILITIES     RECOVERY      ANNUALIZED       OR SAVINGS(-)
                                            COST                       CREDIT    COST OR CREDIT(-)     PER SCFM
                   SCFM         (000)       (000)         (000)        (000)           (000)            $/SCFM

0.0000$/1000 SCF
                    300.          58.         17.           4.           0.             21.             71.32
                   1000.         144.         42.          15.           0.             57.             57.01
                   5000.         273.         81.          74.           0.            155.             31.09
                  20000.         594.        179.         297.           0.            475.             23.76
                  50000.         955.        293.         741.           0.           1034.             20.68
                 100000.        1671.        513.        1483.           0.           1996.             19.96
0.0250$/1000 SCF
                    300.          58.         17.           4.           4.             17.             58.18
                   1000.         144.         42.          15.          13.             44.             43.87
                   5000.         273.         81.          74.          66.             90.             17.95
                  20000.         594.        179.         297.         263.            212.             10.62
                  50000.         955.        293.         741.         657.            377.              7.54
                 100000.        1671.        513.        1483.        1314.            682.              6.82
0.0500$/1000 SCF
                    300.          58.         17.           4.           8.             14.             45.04
                   1000.         144.         42.          15.          26.             31.             30.73
                   5000.         273.         81.          74.         131.             24.              4.81
                  20000.         594.        179.         297.         526.            -50.             -2.52
                  50000.         955.        293.         741.        1314.           -280.             -5.60
                 100000.        1671.        513.        1483.        2628.           -632.             -6.32
0.1000$/1000 SCF
                    300.          58.         17.           4.          16.              6.             18.76
                   1000.         144.         42.          15.          53.              4.              4.45
                   5000.         273.         81.          74.         263.           -107.            -21.47
                  20000.         594.        179.         297.        1051.           -576.            -28.80
                  50000.         955.        293.         741.        2628.          -1594.            -31.88
                 100000.        1671.        513.        1483.        5256.          -3260.            -32.60
0.2000$/1000 SCF
                    300.          58.         17.           4.          32.            -10.            -33.80
                   1000.         144.         42.          15.         105.            -48.            -48.11
                   5000.         273.         81.          74.         526.           -370.            -74.03
                  20000.         594.        179.         297.        2102.          -1627.            -81.36
                  50000.         955.        293.         741.        5256.          -4222.            -84.44
                 100000.        1671.        513.        1483.       10512.          -8516.            -85.16
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OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON   AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	9.	0.	26.	85.17
	1000.	144.	42.	29.	0.	71.	70.86
	5000.	273.	81.	143.	0.	225.	44.93
	20000.	594.	179.	574.	0.	752.	37.61
	50000.	955.	293.	1434.	0.	1727.	34.53
	100000.	1671.	513.	2868.	0.	3381.	33.81
0.0250$/1000 SCF							
	300.	58.	17.	9.	4.	22.	72.03
	1000.	144.	42.	29.	13.	58.	57.72
	5000.	273.	81.	143.	66.	159.	31.79
	20000.	594.	179.	574.	263.	489.	24.47
	50000.	955.	293.	1434.	657.	1070.	21.39
	100000.	1671.	513.	2868.	1314.	2067.	20.67
0.0500$/1000 SCF							
	300.	58.	17.	9.	8.	18.	58.89
	1000.	144.	42.	29.	26.	45.	44.58
	5000.	273.	81.	143.	131.	93.	18.65
	20000.	594.	179.	574.	526.	227.	11.33
	50000.	955.	293.	1434.	1314.	413.	8.25
	100000.	1671.	513.	2868.	2628.	753.	7.53
0.1000$/1000 SCF							
	300.	58.	17.	9.	16.	10.	32.61
	1000.	144.	42.	29.	53.	18.	18.30
	5000.	273.	81.	143.	263.	-38.	-7.63
	20000.	594.	179.	574.	1051.	-299.	-14.95
	50000.	955.	293.	1434.	2628.	-901.	-18.03
	100000.	1671.	513.	2868.	5256.	-1875.	-18.75
0.2000$/1000 SCF							
	300.	58.	17.	9.	32.	-6.	-19.95
	1000.	144.	42.	29.	105.	-34.	-34.26
	5000.	273.	81.	143.	526.	-301.	-60.19
	20000.	594.	179.	574.	2102.	-1350.	-67.51
	50000.	955.	293.	1434.	5256.	-3529.	-70.59
	100000.	1671.	513.	2868.	10512.	-7131.	-71.31

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	OPERATING COST-OR-CREDIT RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	2.	0.	19.	63.25
	1000.	144.	42.	7.	0.	49.	48.95
	5000.	273.	81.	34.	0.	115.	23.02
	20000.	594.	179.	135.	0.	314.	15.69
	50000.	955.	293.	338.	0.	631.	12.62
	100000.	1671.	513.	676.	0.	1189.	11.89
0.0348$/1000 SCF							
	300.	58.	17.	2.	5.	13.	44.96
	1000.	144.	42.	7.	18.	31.	30.65
	5000.	273.	81.	34.	91.	24.	4.73
	20000.	594.	179.	135.	366.	-52.	-2.60
	50000.	955.	293.	338.	915.	-284.	-5.67
	100000.	1671.	513.	676.	1829.	-640.	-6.40
0.0696$/1000 SCF							
	300.	58.	17.	2.	11.	8.	26.67
	1000.	144.	42.	7.	37.	12.	12.36
	5000.	273.	81.	34.	183.	-68.	-13.56
	20000.	594.	179.	135.	732.	-418.	-20.89
	50000.	955.	293.	338.	1829.	-1198.	-23.96
	100000.	1671.	513.	676.	3658.	-2469.	-24.69
0.1392$/1000 SCF							
	300.	58.	17.	2.	22.	-3.	-9.91
	1000.	144.	42.	7.	73.	-24.	-24.22
	5000.	273.	81.	34.	366.	-251.	-50.14
	20000.	594.	179.	135.	1463.	-1149.	-57.47
	50000.	955.	293.	338.	3658.	-3027.	-60.54
	100000.	1671.	513.	676.	7316.	-6127.	-61.27
0.2784$/1000 SCF							
	300.	58.	17.	2.	44.	-25.	-83.08
	1000.	144.	42.	7.	146.	-97.	-97.38
	5000.	273.	81.	34.	732.	-617.	-123.31
	20000.	594.	179.	135.	2927.	-2613.	-130.63
	50000.	955.	293.	338.	7316.	-6685.	-133.71
	100000.	1671.	513.	676.	14633.	-13444.	-134.44

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	4.	0.	21.	69.04
	1000.	144.	42.	13.	0.	55.	54.73
	5000.	273.	81.	63.	0.	144.	28.80
	20000.	594.	179.	251.	0.	430.	21.48
	50000.	955.	293.	627.	0.	920.	18.40
	100000.	1671.	513.	1255.	0.	1767.	17.67
0.0348$/1000 SCF	300.	58.	17.	4.	5.	15.	50.74
	1000.	144.	42.	13.	18.	36.	36.44
	5000.	273.	81.	63.	91.	53.	10.51
	20000.	594.	179.	251.	366.	64.	3.19
	50000.	955.	293.	627.	915.	6.	0.11
	100000.	1671.	513.	1255.	1829.	-62.	-0.62
0.0696$/1000 SCF	300.	58.	17.	4.	11.	10.	32.45
	1000.	144.	42.	13.	37.	18.	18.15
	5000.	273.	81.	63.	183.	-39.	-7.78
	20000.	594.	179.	251.	732.	-302.	-15.11
	50000.	955.	293.	627.	1829.	-909.	-18.18
	100000.	1671.	513.	1255.	3658.	-1891.	-18.91
0.1392$/1000 SCF	300.	58.	17.	4.	22.	-1.	-4.13
	1000.	144.	42.	13.	73.	-18.	-18.43
	5000.	273.	81.	63.	366.	-222.	-44.36
	20000.	594.	179.	251.	1463.	-1034.	-51.69
	50000.	955.	293.	627.	3658.	-2738.	-54.76
	100000.	1671.	513.	1255.	7316.	-5549.	-55.49
0.2784$/1000 SCF	300.	58.	17.	4.	44.	-23.	-77.29
	1000.	144.	42.	13.	146.	-92.	-91.60
	5000.	273.	81.	63.	732.	-588.	-117.52
	20000.	594.	179.	251.	2927.	-2497.	-124.85
	50000.	955.	293.	627.	7316.	-6396.	-127.92
	100000.	1671.	513.	1255.	14633.	-12865.	-128.65

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	6.	0.	23.	76.75
	1000.	144.	42.	20.	0.	62.	62.44
	5000.	273.	81.	101.	0.	183.	36.51
	20000.	594.	179.	405.	0.	584.	29.19
	50000.	955.	293.	1013.	0.	1306.	26.11
	100000.	1671.	513.	2026.	0.	2538.	25.38
0.0348$/1000 SCF							
	300.	58.	17.	6.	5.	18.	58.46
	1000.	144.	42.	20.	18.	44.	44.15
	5000.	273.	81.	101.	91.	91.	18.22
	20000.	594.	179.	405.	366.	218.	10.90
	50000.	955.	293.	1013.	915.	391.	7.82
	100000.	1671.	513.	2026.	1829.	709.	7.09
0.0696$/1000 SCF							
	300.	58.	17.	6.	11.	12.	40.16
	1000.	144.	42.	20.	37.	26.	25.86
	5000.	273.	81.	101.	183.	-0.	-0.07
	20000.	594.	179.	405.	732.	-148.	-7.39
	50000.	955.	293.	1013.	1829.	-523.	-10.47
	100000.	1671.	513.	2026.	3658.	-1120.	-11.20
0.1392$/1000 SCF							
	300.	58.	17.	6.	22.	1.	3.58
	1000.	144.	42.	20.	73.	-11.	-10.72
	5000.	273.	81.	101.	366.	-183.	-36.65
	20000.	594.	179.	405.	1463.	-880.	-43.98
	50000.	955.	293.	1013.	3658.	-2352.	-47.05
	100000.	1671.	513.	2026.	7316.	-4778.	-47.78
0.2784$/1000 SCF							
	300.	58.	17.	6.	44.	-21.	-69.58
	1000.	144.	42.	20.	146.	-84.	-83.89
	5000.	273.	81.	101.	732.	-549.	-109.81
	20000.	594.	179.	405.	2927.	-2343.	-117.14
	50000.	955.	293.	1013.	7316.	-6011.	-120.21
	100000.	1671.	513.	2026.	14633.	-12094.	-120.94

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OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	12.	0.	29.	96.03
	1000.	144.	42.	40.	0.	82.	81.72
	5000.	273.	81.	198.	0.	279.	55.79
	20000.	594.	179.	791.	0.	969.	48.47
	50000.	955.	293.	1977.	0.	2270.	45.39
	100000.	1671.	513.	3954.	0.	4466.	44.66
0.0348$/1000 SCF							
	300.	58.	17.	12.	5.	23.	77.73
	1000.	144.	42.	40.	18.	63.	63.43
	5000.	273.	81.	198.	91.	188.	37.50
	20000.	594.	179.	791.	366.	604.	30.18
	50000.	955.	293.	1977.	915.	1355.	27.10
	100000.	1671.	513.	3954.	1829.	2637.	26.37
0.0696$/1000 SCF							
	300.	58.	17.	12.	11.	18.	59.44
	1000.	144.	42.	40.	37.	45.	45.14
	5000.	273.	81.	198.	183.	96.	19.21
	20000.	594.	179.	791.	732.	238.	11.88
	50000.	955.	293.	1977.	1829.	441.	8.81
	100000.	1671.	513.	3954.	3658.	808.	8.08
0.1392$/1000 SCF							
	300.	58.	17.	12.	22.	7.	22.86
	1000.	144.	42.	40.	73.	9.	8.56
	5000.	273.	81.	198.	366.	-87.	-17.37
	20000.	594.	179.	791.	1463.	-494.	-24.70
	50000.	955.	293.	1977.	3658.	-1389.	-27.77
	100000.	1671.	513.	3954.	7316.	-2850.	-28.50
0.2784$/1000 SCF							
	300.	58.	17.	12.	44.	-15.	-50.30
	1000.	144.	42.	40.	146.	-65.	-64.61
	5000.	273.	81.	198.	732.	-453.	-90.53
	20000.	594.	179.	791.	2927.	-1957.	-97.86
	50000.	955.	293.	1977.	7316.	-5047.	-100.93
	100000.	1671.	513.	3954.	14633.	-10166.	-101.66

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       OFFGAS CARBON REQUIREMENT 8.00  LB CARBON/1000 SCF
       STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON         AT $5.00/MILLION BTU

   CREDIT          OFFGAS      CAPITAL          OPERATING COST-OR-CREDIT           NET              NET COST
                    FLOW        COST       FIXED     UTILITIES     RECOVERY     ANNUALIZED      OR SAVINGS(-)
                                           COST                    CREDIT   COST OR CREDIT(-)    PER SCFM
                    SCFM        (000)      (000)       (000)        (000)         (000)           $/SCFM
0.0000$/1000 SCF
                     300.         58.        17.         2.           0.            19.            64.12
                    1000.        144.        42.         8.           0.            50.            49.81
                    5000.        273.        81.        38.           0.           119.            23.88
                   20000.        594.       179.       153.           0.           331.            16.56
                   50000.        955.       293.       381.           0.           674.            13.48
                  100000.       1671.       513.       763.           0.          1275.            12.75
0.0400$/1000 SCF
                     300.         58.        17.         2.           6.            13.            43.09
                    1000.        144.        42.         8.          21.            29.            28.79
                    5000.        273.        81.        38.         105.            14.             2.86
                   20000.        594.       179.       153.         420.           -89.            -4.47
                   50000.        955.       293.       381.        1051.          -377.            -7.54
                  100000.       1671.       513.       763.        2102.          -827.            -8.27
0.0800$/1000 SCF
                     300.         58.        17.         2.          13.             7.            22.07
                    1000.        144.        42.         8.          42.             8.             7.76
                    5000.        273.        81.        38.         210.           -91.           -18.16
                   20000.        594.       179.       153.         841.          -510.           -25.49
                   50000.        955.       293.       381.        2102.         -1428.           -28.57
                  100000.       1671.       513.       763.        4205.         -2929.           -29.29
0.1600$/1000 SCF
                     300.         58.        17.         2.          25.            -6.           -19.98
                    1000.        144.        42.         8.          84.           -34.           -34.29
                    5000.        273.        81.        38.         420.          -301.           -60.21
                   20000.        594.       179.       153.        1682.         -1351.           -67.54
                   50000.        955.       293.       381.        4205.         -3531.           -70.61
                  100000.       1671.       513.       763.        8410.         -7134.           -71.34
0.3200$/1000 SCF
                     300.         58.        17.         2.          50.           -31.          -104.08
                    1000.        144.        42.         8.         168.          -118.          -118.38
                    5000.        273.        81.        38.         841.          -722.          -144.31
                   20000.        594.       179.       153.        3364.         -3033.          -151.64
                   50000.        955.       293.       381.        8410.         -7735.          -154.71
                  100000.       1671.      .513.       763.       16819.        -15544.          -155.44
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OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	4.	0.	21.	70.76
	1000.	144.	42.	14.	0.	56.	56.46
	5000.	273.	81.	71.	0.	153.	30.53
	20000.	594.	179.	286.	0.	464.	23.20
	50000.	955.	293.	714.	0.	1007.	20.13
	100000.	1671.	513.	1428.	0.	1940.	19.40
0.0400$/1000 SCF							
	300.	58.	17.	4.	6.	15.	49.74
	1000.	144.	42.	14.	21.	35.	35.43
	5000.	273.	81.	71.	105.	48.	9.51
	20000.	594.	179.	286.	420.	44.	2.18
	50000.	955.	293.	714.	1051.	-45.	-0.89
	100000.	1671.	513.	1428.	2102.	-162.	-1.62
0.0800$/1000 SCF							
	300.	58.	17.	4.	13.	9.	28.72
	1000.	144.	42.	14.	42.	14.	14.41
	5000.	273.	81.	71.	210.	-58.	-11.52
	20000.	594.	179.	286.	841.	-377.	-18.84
	50000.	955.	293.	714.	2102.	-1096.	-21.92
	100000.	1671.	513.	1428.	4205.	-2265.	-22.65
0.1600$/1000 SCF							
	300.	58.	17.	4.	25.	-4.	-13.33
	1000.	144.	42.	14.	84.	-28.	-27.64
	5000.	273.	81.	71.	420.	-268.	-53.56
	20000.	594.	179.	286.	1682.	-1218.	-60.89
	50000.	955.	293.	714.	4205.	-3198.	-63.97
	100000.	1671.	513.	1428.	8410.	-6469.	-64.69
0.3200$/1000 SCF							
	300.	58.	17.	4.	50.	-29.	-97.43
	1000.	144.	42.	14.	168.	-112.	-111.73
	5000.	273.	81.	71.	841.	-688.	-137.66
	20000.	594.	179.	286.	3364.	-2900.	-144.99
	50000.	955.	293.	714.	8410.	-7403.	-148.06
	100000.	1671.	513.	1428.	16819.	-14879.	-148.79

OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	7.	0.	24.	79.63
	1000.	144.	42.	23.	0.	65.	65.32
	5000.	273.	81.	116.	0.	197.	39.39
	20000.	594.	179.	463.	0.	641.	32.07
	50000.	955.	293.	1157.	0.	1450.	28.99
	100000.	1671.	513.	2314.	0.	2827.	28.27
0.0400$/1000 SCF							
	300.	58.	17.	7.	6.	18.	58.60
	1000.	144.	42.	23.	21.	44.	44.30
	5000.	273.	81.	116.	105.	92.	18.37
	20000.	594.	179.	463.	420.	221.	11.04
	50000.	955.	293.	1157.	1051.	399.	7.97
	100000.	1671.	513.	2314.	2102.	724.	7.24
0.0800$/1000 SCF							
	300.	58.	17.	7.	13.	11.	37.58
	1000.	144.	42.	23.	42.	23.	23.27
	5000.	273.	81.	116.	210.	-13.	-2.65
	20000.	594.	179.	463.	841.	-200.	-9.98
	50000.	955.	293.	1157.	2102.	-653.	-13.05
	100000.	1671.	513.	2314.	4205.	-1378.	-13.78
0.1600$/1000 SCF							
	300.	58.	17.	7.	25.	-1.	-4.47
	1000.	144.	42.	23.	84.	-19.	-18.78
	5000.	273.	81.	116.	420.	-224.	-44.70
	20000.	594.	179.	463.	1682.	-1041.	-52.03
	50000.	955.	293.	1157.	4205.	-2755.	-55.10
	100000.	1671.	513.	2314.	8410.	-5583.	-55.83
0.3200$/1000 SCF							
	300.	58.	17.	7.	50.	-27.	-88.56
	1000.	144.	42.	23.	168.	-103.	-102.87
	5000.	273.	81.	116.	841.	-644.	-128.80
	20000.	594.	179.	463.	3364.	-2722.	-136.12
	50000.	955.	293.	1157.	8410.	-6960.	-139.20
	100000.	1671.	513.	2314.	16819.	-13993.	-139.93

OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	14.	0.	31.	101.79
	1000.	144.	42.	45.	0.	87.	87.48
	5000.	273.	81.	226.	0.	308.	61.55
	20000.	594.	179.	906.	0.	1085.	54.23
	50000.	955.	293.	2265.	0.	2558.	51.15
	100000.	1671.	513.	4530.	0.	5042.	50.42
0.0400$/1000 SCF							
	300.	58.	17.	14.	6.	24.	80.76
	1000.	144.	42.	45.	21.	66.	66.46
	5000.	273.	81.	226.	105.	203.	40.53
	20000.	594.	179.	906.	420.	664.	33.20
	50000.	955.	293.	2265.	1051.	1506.	30.13
	100000.	1671.	513.	4530.	2102.	2940.	29.40
0.0800$/1000 SCF							
	300.	58.	17.	14.	13.	18.	59.74
	1000.	144.	42.	45.	42.	45.	45.43
	5000.	273.	81.	226.	210.	98.	19.51
	20000.	594.	179.	906.	841.	244.	12.18
	50000.	955.	293.	2265.	2102.	455.	9.11
	100000.	1671.	513.	4530.	4205.	838.	8.38
0.1600$/1000 SCF							
	300.	58.	17.	14.	25.	5.	17.69
	1000.	144.	42.	45.	84.	3.	3.38
	5000.	273.	81.	226.	420.	-113.	-22.54
	20000.	594.	179.	906.	1682.	-597.	-29.87
	50000.	955.	293.	2265.	4205.	-1647.	-32.94
	100000.	1671.	513.	4530.	8410.	-3367.	-33.67
0.3200$/1000 SCF							
	300.	58.	17.	14.	50.	-20.	-66.41
	1000.	144.	42.	45.	168.	-81.	-80.71
	5000.	273.	81.	226.	841.	-533.	-106.64
	20000.	594.	179.	906.	3364.	-2279.	-113.96
	50000.	955.	293.	2265.	8410.	-5852.	-117.04
	100000.	1671.	513.	4530.	16819.	-11777.	-117.77

OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	3.	0.	20.	65.78
	1000.	144.	42.	9.	0.	51.	51.47
	5000.	273.	81.	46.	0.	128.	25.55
	20000.	594.	179.	186.	0.	364.	18.22
	50000.	955.	293.	464.	0.	757.	15.14
	100000.	1671.	513.	929.	0.	1442.	14.42
0.0500$/1000 SCF							
	300.	58.	17.	3.	8.	12.	39.50
	1000.	144.	42.	9.	26.	25.	25.19
	5000.	273.	81.	46.	131.	-4.	-0.73
	20000.	594.	179.	186.	526.	-161.	-8.06
	50000.	955.	293.	464.	1314.	-557.	-11.14
	100000.	1671.	513.	929.	2628.	-1186.	-11.86
0.1000$/1000 SCF							
	300.	58.	17.	3.	16.	4.	13.22
	1000.	144.	42.	9.	53.	-1.	-1.09
	5000.	273.	81.	46.	263.	-135.	-27.01
	20000.	594.	179.	186.	1051.	-687.	-34.34
	50000.	955.	293.	464.	2628.	-1871.	-37.42
	100000.	1671.	513.	929.	5256.	-3814.	-38.14
0.2000$/1000 SCF							
	300.	58.	17.	3.	32.	-12.	-39.34
	1000.	144.	42.	9.	105.	-54.	-53.65
	5000.	273.	81.	46.	526.	-398.	-79.57
	20000.	594.	179.	186.	2102.	-1738.	-86.90
	50000.	955.	293.	464.	5256.	-4499.	-89.98
	100000.	1671.	513.	929.	10512.	-9070.	-90.70
0.4000$/1000 SCF							
	300.	58.	17.	3.	63.	-43.	-144.46
	1000.	144.	42.	9.	210.	-159.	-158.77
	5000.	273.	81.	46.	1051.	-923.	-184.69
	20000.	594.	179.	186.	4205.	-3840.	-192.02
	50000.	955.	293.	464.	10512.	-9755.	-195.10
	100000.	1671.	513.	929.	21024.	-19582.	-195.82

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OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON   AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	5.	0.	22.	74.09
	1000.	144.	42.	18.	0.	60.	59.78
	5000.	273.	81.	88.	0.	169.	33.85
	20000.	594.	179.	352.	0.	531.	26.53
	50000.	955.	293.	880.	0.	1173.	23.45
	100000.	1671.	513.	1760.	0.	2273.	22.73
0.0500$/1000 SCF							
	300.	58.	17.	5.	8.	14.	47.81
	1000.	144.	42.	18.	26.	34.	33.50
	5000.	273.	81.	88.	131.	38.	7.57
	20000.	594.	179.	352.	526.	5.	0.25
	50000.	955.	293.	880.	1314.	-141.	-2.83
	100000.	1671.	513.	1760.	2628.	-355.	-3.55
0.1000$/1000 SCF							
	300.	58.	17.	5.	16.	6.	21.53
	1000.	144.	42.	18.	53.	7.	7.22
	5000.	273.	81.	88.	263.	-94.	-18.71
	20000.	594.	179.	352.	1051.	-521.	-26.03
	50000.	955.	293.	880.	2628.	-1455.	-29.11
	100000.	1671.	513.	1760.	5256.	-2983.	-29.83
0.2000$/1000 SCF							
	300.	58.	17.	5.	32.	-9.	-31.03
	1000.	144.	42.	18.	105.	-45.	-45.34
	5000.	273.	81.	88.	526.	-356.	-71.27
	20000.	594.	179.	352.	2102.	-1572.	-78.59
	50000.	955.	293.	880.	5256.	-4083.	-81.67
	100000.	1671.	513.	1760.	10512.	-8239.	-82.39
0.4000$/1000 SCF							
	300.	58.	17.	5.	63.	-41.	-136.15
	1000.	144.	42.	18.	210.	-150.	-150.46
	5000.	273.	81.	88.	1051.	-882.	-176.39
	20000.	594.	179.	352.	4205.	-3674.	-183.71
	50000.	955.	293.	880.	10512.	-9339.	-186.79
	100000.	1671.	513.	1760.	21024.	-18751.	-187.51

OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	9.	0.	26.	85.17
	1000.	144.	42.	29.	0.	71.	70.86
	5000.	273.	81.	143.	0.	225.	44.93
	20000.	594.	179.	574.	0.	752.	37.61
	50000.	955.	293.	1434.	0.	1727.	34.53
	100000.	1671.	513.	2868.	0.	3381.	33.81
0.0500$/1000 SCF							
	300.	58.	17.	9.	8.	18.	58.89
	1000.	144.	42.	29.	26.	45.	44.58
	5000.	273.	81.	143.	131.	93.	18.65
	20000.	594.	179.	574.	526.	227.	11.33
	50000.	955.	293.	1434.	1314.	413.	8.25
	100000.	1671.	513.	2868.	2628.	753.	7.53
0.1000$/1000 SCF							
	300.	58.	17.	9.	16.	10.	32.61
	1000.	144.	42.	29.	53.	18.	18.30
	5000.	273.	81.	143.	263.	-38.	-7.63
	20000.	594.	179.	574.	1051.	-299.	-14.95
	50000.	955.	293.	1434.	2628.	-901.	-18.03
	100000.	1671.	513.	2868.	5256.	-1875.	-18.75
0.2000$/1000 SCF							
	300.	58.	17.	9.	32.	-6.	-19.95
	1000.	144.	42.	29.	105.	-34.	-34.26
	5000.	273.	81.	143.	526.	-301.	-60.19
	20000.	594.	179.	574.	2102.	-1350.	-67.51
	50000.	955.	293.	1434.	5256.	-3529.	-70.59
	100000.	1671.	513.	2868.	10512.	-7131.	-71.31
0.4000$/1000 SCF							
	300.	58.	17.	9.	63.	-38.	-125.07
	1000.	144.	42.	29.	210.	-139.	-139.38
	5000.	273.	81.	143.	1051.	-827.	-165.31
	20000.	594.	179.	574.	4205.	-3453.	-172.63
	50000.	955.	293.	1434.	10512.	-8785.	-175.71
	100000.	1671.	513.	2868.	21024.	-17643.	-176.43

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OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $5.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	17.	0.	34.	112.87
	1000.	144.	42.	56.	0.	99.	98.56
	5000.	273.	81.	282.	0.	363.	72.63
	20000.	594.	179.	1128.	0.	1306.	65.31
	50000.	955.	293.	2819.	0.	3112.	62.23
	100000.	1671.	513.	5638.	0.	6150.	61.50
0.0500$/1000 SCF							
	300.	58.	17.	17.	8.	26.	86.59
	1000.	144.	42.	56.	26.	72.	72.28
	5000.	273.	81.	282.	131.	232.	46.35
	20000.	594.	179.	1128.	526.	781.	39.03
	50000.	955.	293.	2819.	1314.	1798.	35.95
	100000.	1671.	513.	5638.	2628.	3522.	35.22
0.1000$/1000 SCF							
	300.	58.	17.	17.	16.	18.	60.31
	1000.	144.	42.	56.	53.	46.	46.00
	5000.	273.	81.	282.	263.	100.	20.07
	20000.	594.	179.	1128.	1051.	255.	12.75
	50000.	955.	293.	2819.	2628.	484.	9.67
	100000.	1671.	513.	5638.	5256.	894.	8.94
0.2000$/1000 SCF							
	300.	58.	17.	17.	32.	2.	7.75
	1000.	144.	42.	56.	105.	-7.	-6.56
	5000.	273.	81.	282.	526.	-162.	-32.49
	20000.	594.	179.	1128.	2102.	-796.	-39.81
	50000.	955.	293.	2819.	5256.	-2144.	-42.89
	100000.	1671.	513.	5638.	10512.	-4362.	-43.62
0.4000$/1000 SCF							
	300.	58.	17.	17.	63.	-29.	-97.37
	1000.	144.	42.	56.	210.	-112.	-111.68
	5000.	273.	81.	282.	1051.	-688.	-137.61
	20000.	594.	179.	1128.	4205.	-2899.	-144.93
	50000.	955.	293.	2819.	10512.	-7400.	-148.01
	100000.	1671.	513.	5638.	21024.	-14874.	-148.74

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.63
	1000.	144.	42.	1.	0.	43.	43.32
	5000.	273.	81.	6.	0.	87.	17.40
	20000.	594.	179.	23.	0.	201.	10.07
	50000.	955.	293.	57.	0.	350.	6.99
	100000.	1671.	513.	114.	0.	627.	6.27
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.36
	1000.	144.	42.	1.	0.	43.	43.06
	5000.	273.	81.	6.	1.	86.	17.13
	20000.	594.	179.	23.	5.	196.	9.81
	50000.	955.	293.	57.	13.	337.	6.73
	100000.	1671.	513.	114.	26.	600.	6.00
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.10
	1000.	144.	42.	1.	1.	43.	42.80
	5000.	273.	81.	6.	3.	84.	16.87
	20000.	594.	179.	23.	11.	191.	9.54
	50000.	955.	293.	57.	26.	323.	6.47
	100000.	1671.	513.	114.	53.	574.	5.74
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.58
	1000.	144.	42.	1.	1.	42.	42.27
	5000.	273.	81.	6.	5.	82.	16.34
	20000.	594.	179.	23.	21.	180.	9.02
	50000.	955.	293.	57.	53.	297.	5.94
	100000.	1671.	513.	114.	105.	521.	5.21
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.53
	1000.	144.	42.	1.	2.	41.	41.22
	5000.	273.	81.	6.	11.	76.	15.29
	20000.	594.	179.	23.	42.	159.	7.97
	50000.	955.	293.	57.	105.	245.	4.89
	100000.	1671.	513.	114.	210.	416.	4.16

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.79
	1000.	144.	42.	1.	0.	43.	43.48
	5000.	273.	81.	6.	0.	88.	17.55
	20000.	594.	179.	26.	0.	205.	10.23
	50000.	955.	293.	65.	0.	358.	7.15
	100000.	1671.	513.	130.	0.	643.	6.43
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.52
	1000.	144.	42.	1.	0.	43.	43.22
	5000.	273.	81.	6.	1.	86.	17.29
	20000.	594.	179.	26.	5.	199.	9.97
	50000.	955.	293.	65.	13.	345.	6.89
	100000.	1671.	513.	130.	26.	616.	6.16
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.26
	1000.	144.	42.	1.	1.	43.	42.95
	5000.	273.	81.	6.	3.	85.	17.03
	20000.	594.	179.	26.	11.	194.	9.70
	50000.	955.	293.	65.	26.	331.	6.63
	100000.	1671.	513.	130.	53.	590.	5.90
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.74
	1000.	144.	42.	1.	1.	42.	42.43
	5000.	273.	81.	6.	5.	83.	16.50
	20000.	594.	179.	26.	21.	184.	9.18
	50000.	955.	293.	65.	53.	305.	6.10
	100000.	1671.	513.	130.	105.	537.	5.37
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.68
	1000.	144.	42.	1.	2.	41.	41.38
	5000.	273.	81.	6.	11.	77.	15.45
	20000.	594.	179.	26.	42.	163.	8.13
	50000.	955.	293.	65.	105.	253.	5.05
	100000.	1671.	513.	130.	210.	432.	4.32

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	0.	0.	17.	58.00
	1000.	144.	42.	2.	0.	44.	43.69
	5000.	273.	81.	8.	0.	89.	17.77
	20000.	594.	179.	30.	0.	209.	10.44
	50000.	955.	293.	76.	0.	368.	7.37
	100000.	1671.	513.	151.	0.	664.	6.64
0.0005$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.74
	1000.	144.	42.	2.	0.	43.	43.43
	5000.	273.	81.	8.	1.	88.	17.50
	20000.	594.	179.	30.	5.	204.	10.18
	50000.	955.	293.	76.	13.	355.	7.10
	100000.	1671.	513.	151.	26.	638.	6.38
0.0010$/1000 SCF							
	300.	58.	17.	0.	0.	17.	57.47
	1000.	144.	42.	2.	1.	43.	43.17
	5000.	273.	81.	8.	3.	86.	17.24
	20000.	594.	179.	30.	11.	198.	9.92
	50000.	955.	293.	76.	26.	342.	6.84
	100000.	1671.	513.	151.	53.	611.	6.11
0.0020$/1000 SCF							
	300.	58.	17.	0.	0.	17.	56.95
	1000.	144.	42.	2.	1.	43.	42.64
	5000.	273.	81.	8.	5.	84.	16.72
	20000.	594.	179.	30.	21.	188.	9.39
	50000.	955.	293.	76.	53.	316.	6.32
	100000.	1671.	513.	151.	105.	559.	5.59
0.0040$/1000 SCF							
	300.	58.	17.	0.	1.	17.	55.90
	1000.	144.	42.	2.	2.	42.	41.59
	5000.	273.	81.	8.	11.	78.	15.66
	20000.	594.	179.	30.	42.	167.	8.34
	50000.	955.	293.	76.	105.	263.	5.26
	100000.	1671.	513.	151.	210.	454.	4.54

OFFGAS CARBON REQUIREMENT 0.10 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	58.53
	1000.	144.	42.	2.	0.	44.	44.23
	5000.	273.	81.	10.	0.	91.	18.30
	20000.	594.	179.	41.	0.	219.	10.97
	50000.	955.	293.	102.	0.	395.	7.90
	100000.	1671.	513.	204.	0.	717.	7.17
0.0005$/1000 SCF							
	300.	58.	17.	1.	0.	17.	58.27
	1000.	144.	42.	2.	0.	44.	43.96
	5000.	273.	81.	10.	1.	90.	18.04
	20000.	594.	179.	41.	5.	214.	10.71
	50000.	955.	293.	102.	13.	382.	7.64
	100000.	1671.	513.	204.	26.	691.	6.91
0.0010$/1000 SCF							
	300.	58.	17.	1.	0.	17.	58.01
	1000.	144.	42.	2.	1.	44.	43.70
	5000.	273.	81.	10.	3.	89.	17.77
	20000.	594.	179.	41.	11.	209.	10.45
	50000.	955.	293.	102.	26.	369.	7.37
	100000.	1671.	513.	204.	53.	664.	6.64
0.0020$/1000 SCF							
	300.	58.	17.	1.	0.	17.	57.48
	1000.	144.	42.	2.	1.	43.	43.17
	5000.	273.	81.	10.	5.	86.	17.25
	20000.	594.	179.	41.	21.	198.	9.92
	50000.	955.	293.	102.	53.	342.	6.85
	100000.	1671.	513.	204.	105.	612.	6.12
0.0040$/1000 SCF							
	300.	58.	17.	1.	1.	17.	56.43
	1000.	144.	42.	2.	2.	42.	42.12
	5000.	273.	81.	10.	11.	81.	16.20
	20000.	594.	179.	41.	42.	177.	8.87
	50000.	955.	293.	102.	105.	290.	5.80
	100000.	1671.	513.	204.	210.	507.	5.07

OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	17.	58.27
	1000.	144.	42.	2.	0.	44.	43.96
	5000.	273.	81.	9.	0.	90.	18.03
	20000.	594.	179.	36.	0.	214.	10.71
	50000.	955.	293.	89.	0.	382.	7.63
	100000.	1671.	513.	178.	0.	690.	6.90
0.0025$/1000 SCF							
	300.	58.	17.	1.	0.	17.	56.95
	1000.	144.	42.	2.	1.	43.	42.65
	5000.	273.	81.	9.	7.	84.	16.72
	20000.	594.	179.	36.	26.	188.	9.39
	50000.	955.	293.	89.	66.	316.	6.32
	100000.	1671.	513.	178.	131.	559.	5.59
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	55.64
	1000.	144.	42.	2.	3.	41.	41.33
	5000.	273.	81.	9.	13.	77.	15.41
	20000.	594.	179.	36.	53.	162.	8.08
	50000.	955.	293.	89.	131.	250.	5.01
	100000.	1671.	513.	178.	263.	428.	4.28
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.01
	1000.	144.	42.	2.	5.	39.	38.70
	5000.	273.	81.	9.	26.	64.	12.78
	20000.	594.	179.	36.	105.	109.	5.45
	50000.	955.	293.	89.	263.	119.	2.38
	100000.	1671.	513.	178.	526.	165.	1.65
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	14.	47.75
	1000.	144.	42.	2.	11.	33.	33.45
	5000.	273.	81.	9.	53.	38.	7.52
	20000.	594.	179.	36.	210.	4.	0.20
	50000.	955.	293.	89.	526.	-144.	-2.88
	100000.	1671.	513.	178.	1051.	-361.	-3.61

OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT			NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
			FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)		
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	59.06
	1000.	144.	42.	3.	0.	45.	44.76
	5000.	273.	81.	13.	0.	94.	18.83
	20000.	594.	179.	52.	0.	230.	11.50
	50000.	955.	293.	129.	0.	422.	8.43
	100000.	1671.	513.	258.	0.	770.	7.70
0.0025$/1000 SCF							
	300.	58.	17.	1.	0.	17.	57.75
	1000.	144.	42.	3.	1.	43.	43.44
	5000.	273.	81.	13.	7.	88.	17.52
	20000.	594.	179.	52.	26.	204.	10.19
	50000.	955.	293.	129.	66.	356.	7.12
	100000.	1671.	513.	258.	131.	639.	6.39
0.0050$/1000 SCF							
	300.	58.	17.	1.	1.	17.	56.44
	1000.	144.	42.	3.	3.	42.	42.13
	5000.	273.	81.	13.	13.	81.	16.20
	20000.	594.	179.	52.	53.	178.	8.88
	50000.	955.	293.	129.	131.	290.	5.80
	100000.	1671.	513.	258.	263.	507.	5.07
0.0100$/1000 SCF							
	300.	58.	17.	1.	2.	16.	53.81
	1000.	144.	42.	3.	5.	40.	39.50
	5000.	273.	81.	13.	26.	68.	13.58
	20000.	594.	179.	52.	105.	125.	6.25
	50000.	955.	293.	129.	263.	159.	3.17
	100000.	1671.	513.	258.	526.	245.	2.45
0.0200$/1000 SCF							
	300.	58.	17.	1.	3.	15.	48.55
	1000.	144.	42.	3.	11.	34.	34.25
	5000.	273.	81.	13.	53.	42.	8.32
	20000.	594.	179.	52.	210.	20.	0.99
	50000.	955.	293.	129.	526.	-104.	-2.08
	100000.	1671.	513.	258.	1051.	-281.	-2.81

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OFFGAS CARBON REQUIREMENT 0.50  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON         AT $10.00/MILLION BTU

   CREDIT          OFFGAS        CAPITAL           OPERATING COST-OR-CREDIT              NET              NET COST
                    FLOW          COST        FIXED       UTILITIES      RECOVERY    ANNUALIZED        OR SAVINGS(-)
                                              COST                       CREDIT    COST OR CREDIT(-)     PER SCFM
                    SCFM          (000)       (000)         (000)         (000)         (000)            $/SCFM
 0.0000$/1000 SCF
                     300.           58.         17.            1.            0.           18.             60.13
                    1000.          144.         42.            4.            0.           46.             45.82
                    5000.          273.         81.           18.            0.           99.             19.89
                   20000.          594.        179.           73.            0.          251.             12.57
                   50000.          955.        293.          182.            0.          475.              9.49
                  100000.         1671.        513.          364.            0.          877.              8.77
 0.0025$/1000 SCF
                     300.           58.         17.            1.            0.           18.             58.81
                    1000.          144.         42.            4.            1.           45.             44.51
                    5000.          273.         81.           18.            7.           93.             18.58
                   20000.          594.        179.           73.           26.          225.             11.25
                   50000.          955.        293.          182.           66.          409.              8.18
                  100000.         1671.        513.          364.          131.          745.              7.45
 0.0050$/1000 SCF
                     300.           58.         17.            1.            1.           17.             57.50
                    1000.          144.         42.            4.            3.           43.             43.19
                    5000.          273.         81.           18.           13.           86.             17.27
                   20000.          594.        179.           73.           53.          199.              9.94
                   50000.          955.        293.          182.          131.          343.              6.87
                  100000.         1671.        513.          364.          263.          614.              6.14
 0.0100$/1000 SCF
                     300.           58.         17.            1.            2.           16.             54.87
                    1000.          144.         42.            4.            5.           41.             40.56
                    5000.          273.         81.           18.           26.           73.             14.64
                   20000.          594.        179.           73.          105.          146.              7.31
                   50000.          955.        293.          182.          263.          212.              4.24
                  100000.         1671.        513.          364.          526.          351.              3.51
 0.0200$/1000 SCF
                     300.           58.         17.            1.            3.           15.             49.62
                    1000.          144.         42.            4.           11.           35.             35.31
                    5000.          273.         81.           18.           53.           47.              9.38
                   20000.          594.        179.           73.          210.           41.              2.06
                   50000.          955.        293.          182.          526.          -51.             -1.02
                  100000.         1671.        513.          364.         1051.         -175.             -1.75
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OFFGAS CARBON REQUIREMENT 0.50 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	2.	0.	19.	62.79
	1000.	144.	42.	6.	0.	48.	48.48
	5000.	273.	81.	31.	0.	113.	22.55
	20000.	594.	179.	126.	0.	305.	15.23
	50000.	955.	293.	315.	0.	608.	12.15
	100000.	1671.	513.	630.	0.	1143.	11.43
0.0025$/1000 SCF	300.	58.	17.	2.	0.	18.	61.47
	1000.	144.	42.	6.	1.	47.	47.17
	5000.	273.	81.	31.	7.	106.	21.24
	20000.	594.	179.	126.	26.	278.	13.91
	50000.	955.	293.	315.	66.	542.	10.84
	100000.	1671.	513.	630.	131.	1011.	10.11
0.0050$/1000 SCF	300.	58.	17.	2.	1.	18.	60.16
	1000.	144.	42.	6.	3.	46.	45.85
	5000.	273.	81.	31.	13.	100.	19.93
	20000.	594.	179.	126.	53.	252.	12.60
	50000.	955.	293.	315.	131.	476.	9.53
	100000.	1671.	513.	630.	263.	880.	8.80
0.0100$/1000 SCF	300.	58.	17.	2.	2.	17.	57.53
	1000.	144.	42.	6.	5.	43.	43.22
	5000.	273.	81.	31.	26.	86.	17.30
	20000.	594.	179.	126.	105.	199.	9.97
	50000.	955.	293.	315.	263.	345.	6.90
	100000.	1671.	513.	630.	526.	617.	6.17
0.0200$/1000 SCF	300.	58.	17.	2.	3.	16.	52.28
	1000.	144.	42.	6.	11.	38.	37.97
	5000.	273.	81.	31.	53.	60.	12.04
	20000.	594.	179.	126.	210.	94.	4.72
	50000.	955.	293.	315.	526.	82.	1.64
	100000.	1671.	513.	630.	1051.	91.	0.91

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	59.06
	1000.	144.	42.	3.	0.	45.	44.76
	5000.	273.	81.	13.	0.	94.	18.83
	20000.	594.	179.	52.	0.	230.	11.50
	50000.	955.	293.	129.	0.	422.	8.43
	100000.	1671.	513.	258.	0.	770.	7.70
0.0050$/1000 SCF	300.	58.	17.	1.	1.	17.	56.44
	1000.	144.	42.	3.	3.	42.	42.13
	5000.	273.	81.	13.	13.	81.	16.20
	20000.	594.	179.	52.	53.	178.	8.88
	50000.	955.	293.	129.	131.	290.	5.80
	100000.	1671.	513.	258.	263.	507.	5.07
0.0100$/1000 SCF	300.	58.	17.	1.	2.	16.	53.81
	1000.	144.	42.	3.	5.	40.	39.50
	5000.	273.	81.	13.	26.	68.	13.58
	20000.	594.	179.	52.	105.	125.	6.25
	50000.	955.	293.	129.	263.	159.	3.17
	100000.	1671.	513.	258.	526.	245.	2.45
0.0200$/1000 SCF	300.	58.	17.	1.	3.	15.	48.55
	1000.	144.	42.	3.	11.	34.	34.25
	5000.	273.	81.	13.	53.	42.	8.32
	20000.	594.	179.	52.	210.	20.	0.99
	50000.	955.	293.	129.	526.	-104.	-2.08
	100000.	1671.	513.	258.	1051.	-281.	-2.81
0.0400$/1000 SCF	300.	58.	17.	1.	6.	11.	38.04
	1000.	144.	42.	3.	21.	24.	23.73
	5000.	273.	81.	13.	105.	-11.	-2.19
	20000.	594.	179.	52.	420.	-190.	-9.52
	50000.	955.	293.	129.	1051.	-630.	-12.59
	100000.	1671.	513.	258.	2102.	-1332.	-13.32

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	60.66
	1000.	144.	42.	4.	0.	46.	46.35
	5000.	273.	81.	21.	0.	102.	20.43
	20000.	594.	179.	83.	0.	262.	13.10
	50000.	955.	293.	209.	0.	501.	10.03
	100000.	1671.	513.	417.	0.	930.	9.30
0.0050$/1000 SCF	300.	58.	17.	1.	1.	17.	58.03
	1000.	144.	42.	4.	3.	44.	43.72
	5000.	273.	81.	21.	13.	89.	17.80
	20000.	594.	179.	83.	53.	209.	10.47
	50000.	955.	293.	209.	131.	370.	7.40
	100000.	1671.	513.	417.	263.	667.	6.67
0.0100$/1000 SCF	300.	58.	17.	1.	2.	17.	55.40
	1000.	144.	42.	4.	5.	41.	41.10
	5000.	273.	81.	21.	26.	76.	15.17
	20000.	594.	179.	83.	105.	157.	7.84
	50000.	955.	293.	209.	263.	239.	4.77
	100000.	1671.	513.	417.	526.	404.	4.04
0.0200$/1000 SCF	300.	58.	17.	1.	3.	15.	50.15
	1000.	144.	42.	4.	11.	36.	35.84
	5000.	273.	81.	21.	53.	50.	9.91
	20000.	594.	179.	83.	210.	52.	2.59
	50000.	955.	293.	209.	526.	-24.	-0.49
	100000.	1671.	513.	417.	1051.	-121.	-1.21
0.0400$/1000 SCF	300.	58.	17.	1.	6.	12.	39.64
	1000.	144.	42.	4.	21.	25.	25.33
	5000.	273.	81.	21.	105.	-3.	-0.60
	20000.	594.	179.	83.	420.	-158.	-7.92
	50000.	955.	293.	209.	1051.	-550.	-11.00
	100000.	1671.	513.	417.	2102.	-1173.	-11.73

OFFGAS CARBON REQUIREMENT 1.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	2.	0.	19.	62.79
	1000.	144.	42.	6.	0.	48.	48.48
	5000.	273.	81.	31.	0.	113.	22.55
	20000.	594.	179.	126.	0.	305.	15.23
	50000.	955.	293.	315.	0.	608.	12.15
	100000.	1671.	513.	630.	0.	1143.	11.43
0.0050$/1000 SCF	300.	58.	17.	2.	1.	18.	60.16
	1000.	144.	42.	6.	3.	46.	45.85
	5000.	273.	81.	31.	13.	100.	19.93
	20000.	594.	179.	126.	53.	252.	12.60
	50000.	955.	293.	315.	131.	476.	9.53
	100000.	1671.	513.	630.	263.	880.	8.80
0.0100$/1000 SCF	300.	58.	17.	2.	2.	17.	57.53
	1000.	144.	42.	6.	5.	43.	43.22
	5000.	273.	81.	31.	26.	86.	17.30
	20000.	594.	179.	126.	105.	199.	9.97
	50000.	955.	293.	315.	263.	345.	6.90
	100000.	1671.	513.	630.	526.	617.	6.17
0.0200$/1000 SCF	300.	58.	17.	2.	3.	16.	52.28
	1000.	144.	42.	6.	11.	38.	37.97
	5000.	273.	81.	31.	53.	60.	12.04
	20000.	594.	179.	126.	210.	94.	4.72
	50000.	955.	293.	315.	526.	82.	1.64
	100000.	1671.	513.	630.	1051.	91.	0.91
0.0400$/1000 SCF	300.	58.	17.	2.	6.	13.	41.76
	1000.	144.	42.	6.	21.	27.	27.46
	5000.	273.	81.	31.	105.	8.	1.53
	20000.	594.	179.	126.	420.	-116.	-5.80
	50000.	955.	293.	315.	1051.	-443.	-8.87
	100000.	1671.	513.	630.	2102.	-960.	-9.60

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        OFFGAS CARBON REQUIREMENT 1.00  LB CARBON/1000 SCF
        STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON          AT $10.00/MILLION BTU

CREDIT           OFFGAS       CAPITAL          OPERATING COST-OR-CREDIT               NET            NET COST
                  FLOW         COST       FIXED       UTILITIES    RECOVERY      ANNUALIZED      OR SAVINGS(-)
                                          COST                      CREDIT    COST OR CREDIT(-)    PER SCFM
                  SCFM         (000)      (000)         (000)       (000)          (000)           $/SCFM

0.0000$/1000 SCF
                   300.          58.        17.           3.           0.            20.            68.11
                  1000.         144.        42.          12.           0.            54.            53.80
                  5000.         273.        81.          58.           0.           139.            27.87
                 20000.         594.       179.         232.           0.           411.            20.55
                 50000.         955.       293.         581.           0.           874.            17.47
                100000.        1671.       513.        1162.           0.          1674.            16.74
0.0050$/1000 SCF
                   300.          58.        17.           3.           1.            20.            65.48
                  1000.         144.        42.          12.           3.            51.            51.17
                  5000.         273.        81.          58.          13.           126.            25.25
                 20000.         594.       179.         232.          53.           358.            17.92
                 50000.         955.       293.         581.         131.           742.            14.85
                100000.        1671.       513.        1162.         263.          1412.            14.12
0.0100$/1000 SCF
                   300.          58.        17.           3.           2.            19.            62.85
                  1000.         144.        42.          12.           5.            49.            48.54
                  5000.         273.        81.          58.          26.           113.            22.62
                 20000.         594.       179.         232.         105.           306.            15.29
                 50000.         955.       293.         581.         263.           611.            12.22
                100000.        1671.       513.        1162.         526.          1149.            11.49
0.0200$/1000 SCF
                   300.          58.        17.           3.           3.            17.            57.59
                  1000.         144.        42.          12.          11.            43.            43.29
                  5000.         273.        81.          58.          53.            87.            17.36
                 20000.         594.       179.         232.         210.           201.            10.04
                 50000.         955.       293.         581.         526.           348.             6.96
                100000.        1671.       513.        1162.        1051.           623.             6.23
0.0400$/1000 SCF
                   300.          58.        17.           3.           6.            14.            47.08
                  1000.         144.        42.          12.          21.            33.            32.78
                  5000.         273.        81.          58.         105.            34.             6.85
                 20000.         594.       179.         232.         420.           -10.            -0.48
                 50000.         955.       293.         581.        1051.          -178.            -3.55
                100000.        1671.       513.        1162.        2102.          -428.            -4.28
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OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	1.	0.	18.	59.69
	1000.	144.	42.	3.	0.	45.	45.38
	5000.	273.	81.	16.	0.	97.	19.46
	20000.	594.	179.	64.	0.	243.	12.13
	50000.	955.	293.	160.	0.	453.	9.06
	100000.	1671.	513.	320.	0.	833.	8.33
0.0070$/1000 SCF							
	300.	58.	17.	1.	1.	17.	56.03
	1000.	144.	42.	3.	4.	42.	41.72
	5000.	273.	81.	16.	18.	79.	15.80
	20000.	594.	179.	64.	73.	169.	8.47
	50000.	955.	293.	160.	183.	270.	5.40
	100000.	1671.	513.	320.	366.	467.	4.67
0.0139$/1000 SCF							
	300.	58.	17.	1.	2.	16.	52.37
	1000.	144.	42.	3.	7.	38.	38.06
	5000.	273.	81.	16.	37.	61.	12.14
	20000.	594.	179.	64.	146.	96.	4.81
	50000.	955.	293.	160.	366.	87.	1.74
	100000.	1671.	513.	320.	732.	101.	1.01
0.0279$/1000 SCF							
	300.	58.	17.	1.	4.	14.	45.05
	1000.	144.	42.	3.	15.	31.	30.74
	5000.	273.	81.	16.	73.	24.	4.82
	20000.	594.	179.	64.	293.	-50.	-2.51
	50000.	955.	293.	160.	732.	-279.	-5.59
	100000.	1671.	513.	320.	1464.	-631.	-6.31
0.0557$/1000 SCF							
	300.	58.	17.	1.	9.	9.	30.40
	1000.	144.	42.	3.	29.	16.	16.10
	5000.	273.	81.	16.	146.	-49.	-9.83
	20000.	594.	179.	64.	586.	-343.	-17.15
	50000.	955.	293.	160.	1464.	-1011.	-20.23
	100000.	1671.	513.	320.	2929.	-2096.	-20.96

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OFFGAS CARBON REQUIREMENT 1.39  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON          AT $10.00/MILLION BTU

CREDIT          OFFGAS      CAPITAL          OPERATING COST-OR-CREDIT              NET                NET COST
                 FLOW        COST       FIXED       UTILITIES      RECOVERY     ANNUALIZED         OR SAVINGS(-)
                                        COST                        CREDIT   COST OR CREDIT(-)      PER SCFM
                 SCFM        (000)      (000)         (000)          (000)         (000)             $/SCFM

0.0000$/1000 SCF
                 300.         58.        17.            2.             0.           19.               61.91
                1000.        144.        42.            5.             0.           48.               47.61
                5000.        273.        81.           27.             0.          108.               21.68
               20000.        594.       179.          109.             0.          287.               14.35
               50000.        955.       293.          271.             0.          564.               11.28
              100000.       1671.       513.          543.             0.         1055.               10.55
0.0070$/1000 SCF
                 300.         58.        17.            2.             1.           17.               58.25
                1000.        144.        42.            5.             4.           44.               43.95
                5000.        273.        81.           27.            18.           90.               18.02
               20000.        594.       179.          109.            73.          214.               10.69
               50000.        955.       293.          271.           183.          381.                7.62
              100000.       1671.       513.          543.           366.          689.                6.89
0.0139$/1000 SCF
                 300.         58.        17.            2.             2.           16.               54.59
                1000.        144.        42.            5.             7.           40.               40.29
                5000.        273.        81.           27.            37.           72.               14.36
               20000.        594.       179.          109.           146.          141.                7.03
               50000.        955.       293.          271.           366.          198.                3.96
              100000.       1671.       513.          543.           732.          323.                3.23
0.0279$/1000 SCF
                 300.         58.        17.            2.             4.           14.               47.27
                1000.        144.        42.            5.            15.           33.               32.96
                5000.        273.        81.           27.            73.           35.                7.04
               20000.        594.       179.          109.           293.           -6.               -0.29
               50000.        955.       293.          271.           732.         -168.               -3.36
              100000.       1671.       513.          543.          1464.         -409.               -4.09
0.0557$/1000 SCF
                 300.         58.        17.            2.             9.           10.               32.63
                1000.        144.        42.            5.            29.           18.               18.32
                5000.        273.        81.           27.           146.          -38.               -7.61
               20000.        594.       179.          109.           586.         -299.              -14.93
               50000.        955.       293.          271.          1464.         -900.              -18.01
              100000.       1671.       513.          543.          2929.        -1873.              -18.73
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OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	3.	0.	19.	64.88
	1000.	144.	42.	8.	0.	51.	50.57
	5000.	273.	81.	42.	0.	123.	24.64
	20000.	594.	179.	168.	0.	346.	17.32
	50000.	955.	293.	419.	0.	712.	14.24
	100000.	1671.	513.	839.	0.	1352.	13.52
0.0070$/1000 SCF	300.	58.	17.	3.	1.	18.	61.22
	1000.	144.	42.	8.	4.	47.	46.91
	5000.	273.	81.	42.	18.	105.	20.98
	20000.	594.	179.	168.	73.	273.	13.66
	50000.	955.	293.	419.	183.	529.	10.58
	100000.	1671.	513.	839.	366.	985.	9.85
0.0139$/1000 SCF	300.	58.	17.	3.	2.	17.	57.56
	1000.	144.	42.	8.	7.	43.	43.25
	5000.	273.	81.	42.	37.	87.	17.32
	20000.	594.	179.	168.	146.	200.	10.00
	50000.	955.	293.	419.	366.	346.	6.92
	100000.	1671.	513.	839.	732.	619.	6.19
0.0279$/1000 SCF	300.	58.	17.	3.	4.	15.	50.23
	1000.	144.	42.	8.	15.	36.	35.93
	5000.	273.	81.	42.	73.	50.	10.00
	20000.	594.	179.	168.	293.	54.	2.68
	50000.	955.	293.	419.	732.	-20.	-0.40
	100000.	1671.	513.	839.	1464.	-113.	-1.13
0.0557$/1000 SCF	300.	58.	17.	3.	9.	11.	35.59
	1000.	144.	42.	8.	29.	21.	21.28
	5000.	273.	81.	42.	146.	-23.	-4.64
	20000.	594.	179.	168.	586.	-239.	-11.97
	50000.	955.	293.	419.	1464.	-752.	-15.04
	100000.	1671.	513.	839.	2929.	-1577.	-15.77

OFFGAS CARBON REQUIREMENT 1.39 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	5.	0.	22.	72.29
	1000.	144.	42.	16.	0.	58.	57.98
	5000.	273.	81.	79.	0.	160.	32.05
	20000.	594.	179.	316.	0.	495.	24.73
	50000.	955.	293.	790.	0.	1083.	21.65
	100000.	1671.	513.	1580.	0.	2093.	20.93
0.0070$/1000 SCF	300.	58.	17.	5.	1.	21.	68.63
	1000.	144.	42.	16.	4.	54.	54.32
	5000.	273.	81.	79.	18.	142.	28.39
	20000.	594.	179.	316.	73.	421.	21.07
	50000.	955.	293.	790.	183.	900.	17.99
	100000.	1671.	513.	1580.	366.	1726.	17.26
0.0139$/1000 SCF	300.	58.	17.	5.	2.	19.	64.97
	1000.	144.	42.	16.	7.	51.	50.66
	5000.	273.	81.	79.	37.	124.	24.73
	20000.	594.	179.	316.	146.	348.	17.41
	50000.	955.	293.	790.	366.	717.	14.33
	100000.	1671.	513.	1580.	732.	1360.	13.60
0.0279$/1000 SCF	300.	58.	17.	5.	4.	17.	57.64
	1000.	144.	42.	16.	15.	43.	43.34
	5000.	273.	81.	79.	73.	87.	17.41
	20000.	594.	179.	316.	293.	202.	10.08
	50000.	955.	293.	790.	732.	351.	7.01
	100000.	1671.	513.	1580.	1464.	628.	6.28
0.0557$/1000 SCF	300.	58.	17.	5.	9.	13.	43.00
	1000.	144.	42.	16.	29.	29.	28.69
	5000.	273.	81.	79.	146.	14.	2.77
	20000.	594.	179.	316.	586.	-91.	-4.56
	50000.	955.	293.	790.	1464.	-382.	-7.63
	100000.	1671.	513.	1580.	2929.	-836.	-8.36

OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	1.	0.	18.	60.66
	1000.	144.	42.	4.	0.	46.	46.35
	5000.	273.	81.	21.	0.	102.	20.43
	20000.	594.	179.	83.	0.	262.	13.10
	50000.	955.	293.	209.	0.	501.	10.03
	100000.	1671.	513.	417.	0.	930.	9.30
0.0100$/1000 SCF	300.	58.	17.	1.	2.	17.	55.40
	1000.	144.	42.	4.	5.	41.	41.10
	5000.	273.	81.	21.	26.	76.	15.17
	20000.	594.	179.	83.	105.	157.	7.84
	50000.	955.	293.	209.	263.	239.	4.77
	100000.	1671.	513.	417.	526.	404.	4.04
0.0200$/1000 SCF	300.	58.	17.	1.	3.	15.	50.15
	1000.	144.	42.	4.	11.	36.	35.84
	5000.	273.	81.	21.	53.	50.	9.91
	20000.	594.	179.	83.	210.	52.	2.59
	50000.	955.	293.	209.	526.	-24.	-0.49
	100000.	1671.	513.	417.	1051.	-121.	-1.21
0.0400$/1000 SCF	300.	58.	17.	1.	6.	12.	39.64
	1000.	144.	42.	4.	21.	25.	25.33
	5000.	273.	81.	21.	105.	-3.	-0.60
	20000.	594.	179.	83.	420.	-158.	-7.92
	50000.	955.	293.	209.	1051.	-550.	-11.00
	100000.	1671.	513.	417.	2102.	-1173.	-11.73
0.0800$/1000 SCF	300.	58.	17.	1.	13.	6.	18.61
	1000.	144.	42.	4.	42.	4.	4.30
	5000.	273.	81.	21.	210.	-108.	-21.62
	20000.	594.	179.	83.	841.	-579.	-28.95
	50000.	955.	293.	209.	2102.	-1601.	-32.02
	100000.	1671.	513.	417.	4205.	-3275.	-32.75

OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	2.	0.	19.	63.85
	1000.	144.	42.	7.	0.	50.	49.54
	5000.	273.	81.	37.	0.	118.	23.62
	20000.	594.	179.	147.	0.	326.	16.29
	50000.	955.	293.	368.	0.	661.	13.22
	100000.	1671.	513.	736.	0.	1249.	12.49
0.0100$/1000 SCF							
	300.	58.	17.	2.	2.	18.	58.59
	1000.	144.	42.	7.	5.	44.	44.29
	5000.	273.	81.	37.	26.	92.	18.36
	20000.	594.	179.	147.	105.	221.	11.04
	50000.	955.	293.	368.	263.	398.	7.96
	100000.	1671.	513.	736.	526.	723.	7.23
0.0200$/1000 SCF							
	300.	58.	17.	2.	3.	16.	53.34
	1000.	144.	42.	7.	11.	39.	39.03
	5000.	273.	81.	37.	53.	66.	13.11
	20000.	594.	179.	147.	210.	116.	5.78
	50000.	955.	293.	368.	526.	135.	2.71
	100000.	1671.	513.	736.	1051.	198.	1.98
0.0400$/1000 SCF							
	300.	58.	17.	2.	6.	13.	42.83
	1000.	144.	42.	7.	21.	29.	28.52
	5000.	273.	81.	37.	105.	13.	2.59
	20000.	594.	179.	147.	420.	-95.	-4.73
	50000.	955.	293.	368.	1051.	-390.	-7.81
	100000.	1671.	513.	736.	2102.	-853.	-8.53
0.0800$/1000 SCF							
	300.	58.	17.	2.	13.	7.	21.80
	1000.	144.	42.	7.	42.	7.	7.50
	5000.	273.	81.	37.	210.	-92.	-18.43
	20000.	594.	179.	147.	841.	-515.	-25.76
	50000.	955.	293.	368.	2102.	-1441.	-28.83
	100000.	1671.	513.	736.	4205.	-2956.	-29.56

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        OFFGAS CARBON REQUIREMENT 2.00  LB CARBON/1000 SCF
        STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON        AT $10.00/MILLION BTU

    CREDIT          OFFGAS       CAPITAL             OPERATING COST-OR-CREDIT                 NET              NET COST
                     FLOW         COST        FIXED          UTILITIES         RECOVERY    ANNUALIZED       OR SAVINGS(-)
                                              COST                              CREDIT   COST OR CREDIT(-)   PER SCFM
                     SCFM         (000)       (000)            (000)            (000)         (000)          $/SCFM

0.0000$/1000 SCF
                      300.          58.         17.              3.               0.            20.           68.11
                     1000.         144.         42.             12.               0.            54.           53.80
                     5000.         273.         81.             58.               0.           139.           27.87
                    20000.         594.        179.            232.               0.           411.           20.55
                    50000.         955.        293.            581.               0.           874.           17.47
                   100000.        1671.        513.           1162.               0.          1674.           16.74
0.0100$/1000 SCF
                      300.          58.         17.              3.               2.            19.           62.85
                     1000.         144.         42.             12.               5.            49.           48.54
                     5000.         273.         81.             58.              26.           113.           22.62
                    20000.         594.        179.            232.             105.           306.           15.29
                    50000.         955.        293.            581.             263.           611.           12.22
                   100000.        1671.        513.           1162.             526.          1149.           11.49
0.0200$/1000 SCF
                      300.          58.         17.              3.               3.            17.           57.59
                     1000.         144.         42.             12.              11.            43.           43.29
                     5000.         273.         81.             58.              53.            87.           17.36
                    20000.         594.        179.            232.             210.           201.           10.04
                    50000.         955.        293.            581.             526.           348.            6.96
                   100000.        1671.        513.           1162.            1051.           623.            6.23
0.0400$/1000 SCF
                      300.          58.         17.              3.               6.            14.           47.08
                     1000.         144.         42.             12.              21.            33.           32.78
                     5000.         273.         81.             58.             105.            34.            6.85
                    20000.         594.        179.            232.             420.           -10.           -0.48
                    50000.         955.        293.            581.            1051.          -178.           -3.55
                   100000.        1671.        513.           1162.            2102.          -428.           -4.28
0.0800$/1000 SCF
                      300.          58.         17.              3.              13.             8.           26.06
                     1000.         144.         42.             12.              42.            12.           11.75
                     5000.         273.         81.             58.             210.           -71.          -14.17
                    20000.         594.        179.            232.             841.          -430.          -21.50
                    50000.         955.        293.            581.            2102.         -1229.          -24.57
                   100000.        1671.        513.           1162.            4205.         -2530.          -25.30
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OFFGAS CARBON REQUIREMENT 2.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	7.	0.	24.	78.74
	1000.	144.	42.	22.	0.	64.	64.44
	5000.	273.	81.	111.	0.	193.	38.51
	20000.	594.	179.	445.	0.	624.	31.19
	50000.	955.	293.	1113.	0.	1406.	28.11
	100000.	1671.	513.	2226.	0.	2738.	27.38
0.0100$/1000 SCF							
	300.	58.	17.	7.	2.	22.	73.49
	1000.	144.	42.	22.	5.	59.	59.18
	5000.	273.	81.	111.	26.	166.	33.26
	20000.	594.	179.	445.	105.	519.	25.93
	50000.	955.	293.	1113.	263.	1143.	22.86
	100000.	1671.	513.	2226.	526.	2213.	22.13
0.0200$/1000 SCF							
	300.	58.	17.	7.	3.	20.	68.23
	1000.	144.	42.	22.	11.	54.	53.93
	5000.	273.	81.	111.	53.	140.	28.00
	20000.	594.	179.	445.	210.	413.	20.67
	50000.	955.	293.	1113.	526.	880.	17.60
	100000.	1671.	513.	2226.	1051.	1687.	16.87
0.0400$/1000 SCF							
	300.	58.	17.	7.	6.	17.	57.72
	1000.	144.	42.	22.	21.	43.	43.41
	5000.	273.	81.	111.	105.	87.	17.49
	20000.	594.	179.	445.	420.	203.	10.16
	50000.	955.	293.	1113.	1051.	354.	7.09
	100000.	1671.	513.	2226.	2102.	636.	6.36
0.0800$/1000 SCF							
	300.	58.	17.	7.	13.	11.	36.70
	1000.	144.	42.	22.	42.	22.	22.39
	5000.	273.	81.	111.	210.	-18.	-3.54
	20000.	594.	179.	445.	841.	-217.	-10.86
	50000.	955.	293.	1113.	2102.	-697.	-13.94
	100000.	1671.	513.	2226.	4205.	-1467.	-14.67

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	3.	0.	20.	65.45
	1000.	144.	42.	9.	0.	51.	51.14
	5000.	273.	81.	45.	0.	126.	25.21
	20000.	594.	179.	179.	0.	358.	17.89
	50000.	955.	293.	448.	0.	741.	14.81
	100000.	1671.	513.	896.	0.	1408.	14.08
0.0250$/1000 SCF							
	300.	58.	17.	3.	4.	16.	52.31
	1000.	144.	42.	9.	13.	38.	38.00
	5000.	273.	81.	45.	66.	60.	12.07
	20000.	594.	179.	179.	263.	95.	4.75
	50000.	955.	293.	448.	657.	84.	1.67
	100000.	1671.	513.	896.	1314.	94.	0.94
0.0500$/1000 SCF							
	300.	58.	17.	3.	8.	12.	39.17
	1000.	144.	42.	9.	26.	25.	24.86
	5000.	273.	81.	45.	131.	-5.	-1.07
	20000.	594.	179.	179.	526.	-168.	-8.39
	50000.	955.	293.	448.	1314.	-573.	-11.47
	100000.	1671.	513.	896.	2628.	-1220.	-12.20
0.1000$/1000 SCF							
	300.	58.	17.	3.	16.	4.	12.89
	1000.	144.	42.	9.	53.	-1.	-1.42
	5000.	273.	81.	45.	263.	-137.	-27.35
	20000.	594.	179.	179.	1051.	-693.	-34.67
	50000.	955.	293.	448.	2628.	-1887.	-37.75
	100000.	1671.	513.	896.	5256.	-3848.	-38.48
0.2000$/1000 SCF							
	300.	58.	17.	3.	32.	-12.	-39.67
	1000.	144.	42.	9.	105.	-54.	-53.98
	5000.	273.	81.	45.	526.	-400.	-79.91
	20000.	594.	179.	179.	2102.	-1745.	-87.23
	50000.	955.	293.	448.	5256.	-4515.	-90.31
	100000.	1671.	513.	896.	10512.	-9104.	-91.04

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	5.	0.	22.	73.43
	1000.	144.	42.	17.	0.	59.	59.12
	5000.	273.	81.	85.	0.	166.	33.19
	20000.	594.	179.	339.	0.	517.	25.87
	50000.	955.	293.	847.	0.	1140.	22.79
	100000.	1671.	513.	1694.	0.	2206.	22.06
0.0250$/1000 SCF	300.	58.	17.	5.	4.	18.	60.29
	1000.	144.	42.	17.	13.	46.	45.98
	5000.	273.	81.	85.	66.	100.	20.05
	20000.	594.	179.	339.	263.	255.	12.73
	50000.	955.	293.	847.	657.	483.	9.65
	100000.	1671.	513.	1694.	1314.	892.	8.92
0.0500$/1000 SCF	300.	58.	17.	5.	8.	14.	47.15
	1000.	144.	42.	17.	26.	33.	32.84
	5000.	273.	81.	85.	131.	35.	6.91
	20000.	594.	179.	339.	526.	-8.	-0.41
	50000.	955.	293.	847.	1314.	-174.	-3.49
	100000.	1671.	513.	1694.	2628.	-422.	-4.22
0.1000$/1000 SCF	300.	58.	17.	5.	16.	6.	20.87
	1000.	144.	42.	17.	53.	7.	6.56
	5000.	273.	81.	85.	263.	-97.	-19.37
	20000.	594.	179.	339.	1051.	-534.	-26.69
	50000.	955.	293.	847.	2628.	-1488.	-29.77
	100000.	1671.	513.	1694.	5256.	-3050.	-30.50
0.2000$/1000 SCF	300.	58.	17.	5.	32.	-10.	-31.69
	1000.	144.	42.	17.	105.	-46.	-46.00
	5000.	273.	81.	85.	526.	-360.	-71.93
	20000.	594.	179.	339.	2102.	-1585.	-79.25
	50000.	955.	293.	847.	5256.	-4116.	-82.33
	100000.	1671.	513.	1694.	10512.	-8306.	-83.06

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	8.	0.	25.	84.06
	1000.	144.	42.	28.	0.	70.	69.76
	5000.	273.	81.	138.	0.	219.	43.83
	20000.	594.	179.	552.	0.	730.	36.50
	50000.	955.	293.	1379.	0.	1672.	33.43
	100000.	1671.	513.	2758.	0.	3270.	32.70
0.0250$/1000 SCF							
	300.	58.	17.	8.	4.	21.	70.92
	1000.	144.	42.	28.	13.	57.	56.62
	5000.	273.	81.	138.	66.	153.	30.69
	20000.	594.	179.	552.	263.	467.	23.36
	50000.	955.	293.	1379.	657.	1015.	20.29
	100000.	1671.	513.	2758.	1314.	1956.	19.56
0.0500$/1000 SCF							
	300.	58.	17.	8.	8.	17.	57.78
	1000.	144.	42.	28.	26.	43.	43.48
	5000.	273.	81.	138.	131.	88.	17.55
	20000.	594.	179.	552.	526.	204.	10.22
	50000.	955.	293.	1379.	1314.	358.	7.15
	100000.	1671.	513.	2758.	2628.	642.	6.42
0.1000$/1000 SCF							
	300.	58.	17.	8.	16.	9.	31.50
	1000.	144.	42.	28.	53.	17.	17.20
	5000.	273.	81.	138.	263.	-44.	-8.73
	20000.	594.	179.	552.	1051.	-321.	-16.06
	50000.	955.	293.	1379.	2628.	-956.	-19.13
	100000.	1671.	513.	2758.	5256.	-1986.	-19.86
0.2000$/1000 SCF							
	300.	58.	17.	8.	32.	-6.	-21.06
	1000.	144.	42.	28.	105.	-35.	-35.36
	5000.	273.	81.	138.	526.	-306.	-61.29
	20000.	594.	179.	552.	2102.	-1372.	-68.62
	50000.	955.	293.	1379.	5256.	-3584.	-71.69
	100000.	1671.	513.	2758.	10512.	-7242.	-72.42

OFFGAS CARBON REQUIREMENT 5.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	16.	0.	33.	110.66
	1000.	144.	42.	54.	0.	96.	96.35
	5000.	273.	81.	271.	0.	352.	70.43
	20000.	594.	179.	1083.	0.	1262.	63.10
	50000.	955.	293.	2709.	0.	3001.	60.03
	100000.	1671.	513.	5417.	0.	5930.	59.30
0.0250$/1000 SCF							
	300.	58.	17.	16.	4.	29.	97.52
	1000.	144.	42.	54.	13.	83.	83.21
	5000.	273.	81.	271.	66.	286.	57.29
	20000.	594.	179.	1083.	263.	999.	49.96
	50000.	955.	293.	2709.	657.	2344.	46.89
	100000.	1671.	513.	5417.	1314.	4616.	46.16
0.0500$/1000 SCF							
	300.	58.	17.	16.	8.	25.	84.38
	1000.	144.	42.	54.	26.	70.	70.07
	5000.	273.	81.	271.	131.	221.	44.15
	20000.	594.	179.	1083.	526.	736.	36.82
	50000.	955.	293.	2709.	1314.	1687.	33.75
	100000.	1671.	513.	5417.	2628.	3302.	33.02
0.1000$/1000 SCF							
	300.	58.	17.	16.	16.	17.	58.10
	1000.	144.	42.	54.	53.	44.	43.79
	5000.	273.	81.	271.	263.	89.	17.87
	20000.	594.	179.	1083.	1051.	211.	10.54
	50000.	955.	293.	2709.	2628.	373.	7.47
	100000.	1671.	513.	5417.	5256.	674.	6.74
0.2000$/1000 SCF							
	300.	58.	17.	16.	32.	2.	5.54
	1000.	144.	42.	54.	105.	-9.	-8.77
	5000.	273.	81.	271.	526.	-173.	-34.69
	20000.	594.	179.	1083.	2102.	-840.	-42.02
	50000.	955.	293.	2709.	5256.	-2255.	-45.09
	100000.	1671.	513.	5417.	10512.	-4582.	-45.82

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	4.	0.	21.	68.57
	1000.	144.	42.	12.	0.	54.	54.27
	5000.	273.	81.	60.	0.	142.	28.34
	20000.	594.	179.	242.	0.	420.	21.02
	50000.	955.	293.	604.	0.	897.	17.94
	100000.	1671.	513.	1209.	0.	1721.	17.21
0.0348$/1000 SCF							
	300.	58.	17.	4.	5.	15.	50.28
	1000.	144.	42.	12.	18.	36.	35.98
	5000.	273.	81.	60.	91.	50.	10.05
	20000.	594.	179.	242.	366.	54.	2.72
	50000.	955.	293.	604.	915.	-17.	-0.35
	100000.	1671.	513.	1209.	1829.	-108.	-1.08
0.0696$/1000 SCF							
	300.	58.	17.	4.	11.	10.	31.99
	1000.	144.	42.	12.	37.	18.	17.69
	5000.	273.	81.	60.	183.	-41.	-8.24
	20000.	594.	179.	242.	732.	-311.	-15.57
	50000.	955.	293.	604.	1829.	-932.	-18.64
	100000.	1671.	513.	1209.	3658.	-1937.	-19.37
0.1392$/1000 SCF							
	300.	58.	17.	4.	22.	-1.	-4.59
	1000.	144.	42.	12.	73.	-19.	-18.90
	5000.	273.	81.	60.	366.	-224.	-44.82
	20000.	594.	179.	242.	1463.	-1043.	-52.15
	50000.	955.	293.	604.	3658.	-2761.	-55.22
	100000.	1671.	513.	1209.	7316.	-5595.	-55.95
0.2784$/1000 SCF							
	300.	58.	17.	4.	44.	-23.	-77.75
	1000.	144.	42.	12.	146.	-92.	-92.06
	5000.	273.	81.	60.	732.	-590.	-117.99
	20000.	594.	179.	242.	2927.	-2506.	-125.31
	50000.	955.	293.	604.	7316.	-6419.	-128.39
	100000.	1671.	513.	1209.	14633.	-12911.	-129.11

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	7.	0.	24.	79.68
	1000.	144.	42.	23.	0.	65.	65.37
	5000.	273.	81.	116.	0.	197.	39.45
	20000.	594.	179.	464.	0.	642.	32.12
	50000.	955.	293.	1160.	0.	1452.	29.05
	100000.	1671.	513.	2319.	0.	2832.	28.32
0.0348$/1000 SCF							
	300.	58.	17.	7.	5.	18.	61.39
	1000.	144.	42.	23.	18.	47.	47.08
	5000.	273.	81.	116.	91.	106.	21.16
	20000.	594.	179.	464.	366.	277.	13.83
	50000.	955.	293.	1160.	915.	538.	10.76
	100000.	1671.	513.	2319.	1829.	1003.	10.03
0.0696$/1000 SCF							
	300.	58.	17.	7.	11.	13.	43.10
	1000.	144.	42.	23.	37.	29.	28.79
	5000.	273.	81.	116.	183.	14.	2.87
	20000.	594.	179.	464.	732.	-89.	-4.46
	50000.	955.	293.	1160.	1829.	-377.	-7.53
	100000.	1671.	513.	2319.	3658.	-826.	-8.26
0.1392$/1000 SCF							
	300.	58.	17.	7.	22.	2.	6.52
	1000.	144.	42.	23.	73.	-8.	-7.79
	5000.	273.	81.	116.	366.	-169.	-33.72
	20000.	594.	179.	464.	1463.	-821.	-41.04
	50000.	955.	293.	1160.	3658.	-2206.	-44.12
	100000.	1671.	513.	2319.	7316.	-4484.	-44.84
0.2784$/1000 SCF							
	300.	58.	17.	7.	44.	-20.	-66.65
	1000.	144.	42.	23.	146.	-81.	-80.95
	5000.	273.	81.	116.	732.	-534.	-106.88
	20000.	594.	179.	464.	2927.	-2284.	-114.21
	50000.	955.	293.	1160.	7316.	-5864.	-117.28
	100000.	1671.	513.	2319.	14633.	-11801.	-118.01

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	11.	0.	28.	94.49
	1000.	144.	42.	38.	0.	80.	80.18
	5000.	273.	81.	190.	0.	271.	54.26
	20000.	594.	179.	760.	0.	939.	46.93
	50000.	955.	293.	1900.	0.	2193.	43.86
	100000.	1671.	513.	3800.	0.	4313.	43.13
0.0348$/1000 SCF							
	300.	58.	17.	11.	5.	23.	76.20
	1000.	144.	42.	38.	18.	62.	61.89
	5000.	273.	81.	190.	91.	180.	35.97
	20000.	594.	179.	760.	366.	573.	28.64
	50000.	955.	293.	1900.	915.	1278.	25.57
	100000.	1671.	513.	3800.	1829.	2484.	24.84
0.0696$/1000 SCF							
	300.	58.	17.	11.	11.	17.	57.91
	1000.	144.	42.	38.	37.	44.	43.60
	5000.	273.	81.	190.	183.	88.	17.67
	20000.	594.	179.	760.	732.	207.	10.35
	50000.	955.	293.	1900.	1829.	364.	7.27
	100000.	1671.	513.	3800.	3658.	655.	6.55
0.1392$/1000 SCF							
	300.	58.	17.	11.	22.	6.	21.33
	1000.	144.	42.	38.	73.	7.	7.02
	5000.	273.	81.	190.	366.	-95.	-18.91
	20000.	594.	179.	760.	1463.	-525.	-26.23
	50000.	955.	293.	1900.	3658.	-1465.	-29.31
	100000.	1671.	513.	3800.	7316.	-3004.	-30.04
0.2784$/1000 SCF							
	300.	58.	17.	11.	44.	-16.	-51.84
	1000.	144.	42.	38.	146.	-66.	-66.14
	5000.	273.	81.	190.	732.	-460.	-92.07
	20000.	594.	179.	760.	2927.	-1988.	-99.40
	50000.	955.	293.	1900.	7316.	-5124.	-102.47
	100000.	1671.	513.	3800.	14633.	-10320.	-103.20

OFFGAS CARBON REQUIREMENT 6.96 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	23.	0.	39.	131.51
	1000.	144.	42.	75.	0.	117.	117.20
	5000.	273.	81.	375.	0.	456.	91.28
	20000.	594.	179.	1500.	0.	1679.	83.95
	50000.	955.	293.	3751.	0.	4044.	80.88
	100000.	1671.	513.	7502.	0.	8015.	80.15
0.0348$/1000 SCF							
	300.	58.	17.	23.	5.	34.	113.22
	1000.	144.	42.	75.	18.	99.	98.91
	5000.	273.	81.	375.	91.	365.	72.99
	20000.	594.	179.	1500.	366.	1313.	65.66
	50000.	955.	293.	3751.	915.	3129.	62.59
	100000.	1671.	513.	7502.	1829.	6186.	61.86
0.0696$/1000 SCF							
	300.	58.	17.	23.	11.	28.	94.93
	1000.	144.	42.	75.	37.	81.	80.62
	5000.	273.	81.	375.	183.	273.	54.70
	20000.	594.	179.	1500.	732.	947.	47.37
	50000.	955.	293.	3751.	1829.	2215.	44.29
	100000.	1671.	513.	7502.	3658.	4357.	43.57
0.1392$/1000 SCF							
	300.	58.	17.	23.	22.	18.	58.35
	1000.	144.	42.	75.	73.	44.	44.04
	5000.	273.	81.	375.	366.	91.	18.11
	20000.	594.	179.	1500.	1463.	216.	10.79
	50000.	955.	293.	3751.	3658.	386.	7.71
	100000.	1671.	513.	7502.	7316.	698.	6.98
0.2784$/1000 SCF							
	300.	58.	17.	23.	44.	-4.	-14.82
	1000.	144.	42.	75.	146.	-29.	-29.12
	5000.	273.	81.	375.	732.	-275.	-55.05
	20000.	594.	179.	1500.	2927.	-1248.	-62.38
	50000.	955.	293.	3751.	7316.	-3273.	-65.45
	100000.	1671.	513.	7502.	14633.	-6618.	-66.18

OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	4.	0.	21.	70.23
	1000.	144.	42.	14.	0.	56.	55.93
	5000.	273.	81.	69.	0.	150.	30.00
	20000.	594.	179.	275.	0.	453.	22.67
	50000.	955.	293.	687.	0.	980.	19.60
	100000.	1671.	513.	1375.	0.	1887.	18.87
0.0400$/1000 SCF							
	300.	58.	17.	4.	6.	15.	49.21
	1000.	144.	42.	14.	21.	35.	34.90
	5000.	273.	81.	69.	105.	45.	8.98
	20000.	594.	179.	275.	420.	33.	1.65
	50000.	955.	293.	687.	1051.	-71.	-1.42
	100000.	1671.	513.	1375.	2102.	-215.	-2.15
0.0800$/1000 SCF							
	300.	58.	17.	4.	13.	8.	28.19
	1000.	144.	42.	14.	42.	14.	13.88
	5000.	273.	81.	69.	210.	-60.	-12.05
	20000.	594.	179.	275.	841.	-387.	-19.37
	50000.	955.	293.	687.	2102.	-1122.	-22.45
	100000.	1671.	513.	1375.	4205.	-2318.	-23.18
0.1600$/1000 SCF							
	300.	58.	17.	4.	25.	-4.	-13.86
	1000.	144.	42.	14.	84.	-28.	-28.17
	5000.	273.	81.	69.	420.	-270.	-54.09
	20000.	594.	179.	275.	1682.	-1228.	-61.42
	50000.	955.	293.	687.	4205.	-3225.	-64.50
	100000.	1671.	513.	1375.	8410.	-6522.	-65.22
0.3200$/1000 SCF							
	300.	58.	17.	4.	50.	-29.	-97.96
	1000.	144.	42.	14.	168.	-112.	-112.26
	5000.	273.	81.	69.	841.	-691.	-138.19
	20000.	594.	179.	275.	3364.	-2910.	-145.52
	50000.	955.	293.	687.	8410.	-7430.	-148.59
	100000.	1671.	513.	1375.	16819.	-14932.	-149.32

OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	8.	0.	25.	83.00
	1000.	144.	42.	27.	0.	69.	68.69
	5000.	273.	81.	133.	0.	214.	42.77
	20000.	594.	179.	530.	0.	709.	35.44
	50000.	955.	293.	1326.	0.	1618.	32.37
	100000.	1671.	513.	2651.	0.	3164.	31.64
0.0400$/1000 SCF							
	300.	58.	17.	8.	6.	19.	61.98
	1000.	144.	42.	27.	21.	48.	47.67
	5000.	273.	81.	133.	105.	109.	21.74
	20000.	594.	179.	530.	420.	288.	14.42
	50000.	955.	293.	1326.	1051.	567.	11.34
	100000.	1671.	513.	2651.	2102.	1061.	10.61
0.0800$/1000 SCF							
	300.	58.	17.	8.	13.	12.	40.95
	1000.	144.	42.	27.	42.	27.	26.64
	5000.	273.	81.	133.	210.	4.	0.72
	20000.	594.	179.	530.	841.	-132.	-6.61
	50000.	955.	293.	1326.	2102.	-484.	-9.68
	100000.	1671.	513.	2651.	4205.	-1041.	-10.41
0.1600$/1000 SCF							
	300.	58.	17.	8.	25.	-0.	-1.10
	1000.	144.	42.	27.	84.	-15.	-15.40
	5000.	273.	81.	133.	420.	-207.	-41.33
	20000.	594.	179.	530.	1682.	-973.	-48.66
	50000.	955.	293.	1326.	4205.	-2586.	-51.73
	100000.	1671.	513.	2651.	8410.	-5246.	-52.46
0.3200$/1000 SCF							
	300.	58.	17.	8.	50.	-26.	-85.19
	1000.	144.	42.	27.	168.	-99.	-99.50
	5000.	273.	81.	133.	841.	-627.	-125.43
	20000.	594.	179.	530.	3364.	-2655.	-132.75
	50000.	955.	293.	1326.	8410.	-6791.	-135.83
	100000.	1671.	513.	2651.	16819.	-13655.	-136.55

OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	13.	0.	30.	100.02
	1000.	144.	42.	44.	0.	86.	85.71
	5000.	273.	81.	218.	0.	299.	59.79
	20000.	594.	179.	871.	0.	1049.	52.46
	50000.	955.	293.	2177.	0.	2469.	49.39
	100000.	1671.	513.	4353.	0.	4866.	48.66
0.0400$/1000 SCF							
	300.	58.	17.	13.	6.	24.	79.00
	1000.	144.	42.	44.	21.	65.	64.69
	5000.	273.	81.	218.	105.	194.	38.76
	20000.	594.	179.	871.	420.	629.	31.44
	50000.	955.	293.	2177.	1051.	1418.	28.36
	100000.	1671.	513.	4353.	2102.	2763.	27.63
0.0800$/1000 SCF							
	300.	58.	17.	13.	13.	17.	57.97
	1000.	144.	42.	44.	42.	44.	43.67
	5000.	273.	81.	218.	210.	89.	17.74
	20000.	594.	179.	871.	841.	208.	10.41
	50000.	955.	293.	2177.	2102.	367.	7.34
	100000.	1671.	513.	4353.	4205.	661.	6.61
0.1600$/1000 SCF							
	300.	58.	17.	13.	25.	5.	15.92
	1000.	144.	42.	44.	84.	2.	1.62
	5000.	273.	81.	218.	420.	-122.	-24.31
	20000.	594.	179.	871.	1682.	-633.	-31.63
	50000.	955.	293.	2177.	4205.	-1735.	-34.71
	100000.	1671.	513.	4353.	8410.	-3544.	-35.44
0.3200$/1000 SCF							
	300.	58.	17.	13.	50.	-20.	-68.17
	1000.	144.	42.	44.	168.	-82.	-82.48
	5000.	273.	81.	218.	841.	-542.	-108.40
	20000.	594.	179.	871.	3364.	-2315.	-115.73
	50000.	955.	293.	2177.	8410.	-5940.	-118.80
	100000.	1671.	513.	4353.	16819.	-11953.	-119.53

OFFGAS CARBON REQUIREMENT 8.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	26.	0.	43.	142.57
	1000.	144.	42.	86.	0.	128.	128.27
	5000.	273.	81.	430.	0.	512.	102.34
	20000.	594.	179.	1722.	0.	1900.	95.01
	50000.	955.	293.	4304.	0.	4597.	91.94
	100000.	1671.	513.	8609.	0.	9121.	91.21
0.0400$/1000 SCF							
	300.	58.	17.	26.	6.	36.	121.55
	1000.	144.	42.	86.	21.	107.	107.24
	5000.	273.	81.	430.	105.	407.	81.32
	20000.	594.	179.	1722.	420.	1480.	73.99
	50000.	955.	293.	4304.	1051.	3546.	70.92
	100000.	1671.	513.	8609.	2102.	7019.	70.19
0.0800$/1000 SCF							
	300.	58.	17.	26.	13.	30.	100.53
	1000.	144.	42.	86.	42.	86.	86.22
	5000.	273.	81.	430.	210.	301.	60.29
	20000.	594.	179.	1722.	841.	1059.	52.97
	50000.	955.	293.	4304.	2102.	2495.	49.89
	100000.	1671.	513.	8609.	4205.	4916.	49.16
0.1600$/1000 SCF							
	300.	58.	17.	26.	25.	18.	58.48
	1000.	144.	42.	86.	84.	44.	44.17
	5000.	273.	81.	430.	420.	91.	18.24
	20000.	594.	179.	1722.	1682.	218.	10.92
	50000.	955.	293.	4304.	4205.	392.	7.84
	100000.	1671.	513.	8609.	8410.	712.	7.12
0.3200$/1000 SCF							
	300.	58.	17.	26.	50.	-8.	-25.62
	1000.	144.	42.	86.	168.	-40.	-39.93
	5000.	273.	81.	430.	841.	-329.	-65.85
	20000.	594.	179.	1722.	3364.	-1464.	-73.18
	50000.	955.	293.	4304.	8410.	-3813.	-76.25
	100000.	1671.	513.	8609.	16819.	-7698.	-76.98

OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.3 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF							
	300.	58.	17.	5.	0.	22.	73.43
	1000.	144.	42.	17.	0.	59.	59.12
	5000.	273.	81.	85.	0.	166.	33.19
	20000.	594.	179.	339.	0.	517.	25.87
	50000.	955.	293.	847.	0.	1140.	22.79
	100000.	1671.	513.	1694.	0.	2206.	22.06
0.0500$/1000 SCF							
	300.	58.	17.	5.	8.	14.	47.15
	1000.	144.	42.	17.	26.	33.	32.84
	5000.	273.	81.	85.	131.	35.	6.91
	20000.	594.	179.	339.	526.	-8.	-0.41
	50000.	955.	293.	847.	1314.	-174.	-3.49
	100000.	1671.	513.	1694.	2628.	-422.	-4.22
0.1000$/1000 SCF							
	300.	58.	17.	5.	16.	6.	20.87
	1000.	144.	42.	17.	53.	7.	6.56
	5000.	273.	81.	85.	263.	-97.	-19.37
	20000.	594.	179.	339.	1051.	-534.	-26.69
	50000.	955.	293.	847.	2628.	-1488.	-29.77
	100000.	1671.	513.	1694.	5256.	-3050.	-30.50
0.2000$/1000 SCF							
	300.	58.	17.	5.	32.	-10.	-31.69
	1000.	144.	42.	17.	105.	-46.	-46.00
	5000.	273.	81.	85.	526.	-360.	-71.93
	20000.	594.	179.	339.	2102.	-1585.	-79.25
	50000.	955.	293.	847.	5256.	-4116.	-82.33
	100000.	1671.	513.	1694.	10512.	-8306.	-83.06
0.4000$/1000 SCF							
	300.	58.	17.	5.	63.	-41.	-136.81
	1000.	144.	42.	17.	210.	-151.	-151.12
	5000.	273.	81.	85.	1051.	-885.	-177.05
	20000.	594.	179.	339.	4205.	-3687.	-184.37
	50000.	955.	293.	847.	10512.	-9372.	-187.45
	100000.	1671.	513.	1694.	21024.	-18818.	-188.18

OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 0.6 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT			NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
			FIXED COST (000)	UTILITIES (000)	RECOVERY CREDIT (000)		
0.0000$/1000 SCF	300.	58.	17.	10.	0.	27.	89.38
	1000.	144.	42.	33.	0.	75.	75.08
	5000.	273.	81.	164.	0.	246.	49.15
	20000.	594.	179.	658.	0.	836.	41.82
	50000.	955.	293.	1645.	0.	1937.	38.75
	100000.	1671.	513.	3289.	0.	3802.	38.02
0.0500$/1000 SCF	300.	58.	17.	10.	8.	19.	63.10
	1000.	144.	42.	33.	26.	49.	48.80
	5000.	273.	81.	164.	131.	114.	22.87
	20000.	594.	179.	658.	526.	311.	15.54
	50000.	955.	293.	1645.	1314.	623.	12.47
	100000.	1671.	513.	3289.	2628.	1174.	11.74
0.1000$/1000 SCF	300.	58.	17.	10.	16.	11.	36.82
	1000.	144.	42.	33.	53.	23.	22.52
	5000.	273.	81.	164.	263.	-17.	-3.41
	20000.	594.	179.	658.	1051.	-215.	-10.74
	50000.	955.	293.	1645.	2628.	-691.	-13.81
	100000.	1671.	513.	3289.	5256.	-1454.	-14.54
0.2000$/1000 SCF	300.	58.	17.	10.	32.	-5.	-15.74
	1000.	144.	42.	33.	105.	-30.	-30.04
	5000.	273.	81.	164.	526.	-280.	-55.97
	20000.	594.	179.	658.	2102.	-1266.	-63.30
	50000.	955.	293.	1645.	5256.	-3319.	-66.37
	100000.	1671.	513.	3289.	10512.	-6710.	-67.10
0.4000$/1000 SCF	300.	58.	17.	10.	63.	-36.	-120.86
	1000.	144.	42.	33.	210.	-135.	-135.16
	5000.	273.	81.	164.	1051.	-805.	-161.09
	20000.	594.	179.	658.	4205.	-3368.	-168.42
	50000.	955.	293.	1645.	10512.	-8575.	-171.49
	100000.	1671.	513.	3289.	21024.	-17222.	-172.22

OFFGAS CARBON REQUIREMENT10.00 LB CARBON/1000 SCF
STEAM REGENERATION RATIO 1.0 LB STEAM/ LB CARBON AT $10.00/MILLION BTU

CREDIT	OFFGAS FLOW SCFM	CAPITAL COST (000)	OPERATING COST-OR-CREDIT FIXED COST (000)	OPERATING COST-OR-CREDIT UTILITIES (000)	RECOVERY CREDIT (000)	NET ANNUALIZED COST OR CREDIT(-) (000)	NET COST OR SAVINGS(-) PER SCFM $/SCFM
0.0000$/1000 SCF	300.	58.	17.	16.	0.	33.	110.66
	1000.	144.	42.	54.	0.	96.	96.35
	5000.	273.	81.	271.	0.	352.	70.43
	20000.	594.	179.	1083.	0.	1262.	63.10
	50000.	955.	293.	2709.	0.	3001.	60.03
	100000.	1671.	513.	5417.	0.	5930.	59.30
0.0500$/1000 SCF	300.	58.	17.	16.	8.	25.	84.38
	1000.	144.	42.	54.	26.	70.	70.07
	5000.	273.	81.	271.	131.	221.	44.15
	20000.	594.	179.	1083.	526.	736.	36.82
	50000.	955.	293.	2709.	1314.	1687.	33.75
	100000.	1671.	513.	5417.	2628.	3302.	33.02
0.1000$/1000 SCF	300.	58.	17.	16.	16.	17.	58.10
	1000.	144.	42.	54.	53.	44.	43.79
	5000.	273.	81.	271.	263.	89.	17.87
	20000.	594.	179.	1083.	1051.	211.	10.54
	50000.	955.	293.	2709.	2629.	373.	7.47
	100000.	1671.	513.	5417.	5256.	674.	6.74
0.2000$/1000 SCF	300.	58.	17.	16.	32.	2.	5.54
	1000.	144.	42.	54.	105.	-9.	-8.77
	5000.	273.	81.	271.	526.	-173.	-34.69
	20000.	594.	179.	1083.	2102.	-840.	-42.02
	50000.	955.	293.	2709.	5256.	-2255.	-45.09
	100000.	1671.	513.	5417.	10512.	-4582.	-45.82
0.4000$/1000 SCF	300.	58.	17.	16.	63.	-30.	-99.58
	1000.	144.	42.	54.	210.	-114.	-113.89
	5000.	273.	81.	271.	1051.	-699.	-139.81
	20000.	594.	179.	1083.	4205.	-2943.	-147.14
	50000.	955.	293.	2709.	10512.	-7511.	-150.21
	100000.	1671.	513.	5417.	21024.	-15094.	-150.94

```
OFFGAS CARBON REQUIREMENT10.00  LB CARBON/1000 SCF
STEAM REGENERATION RATIO 2.0 LB STEAM/ LB CARBON          AT $10.00/MILLION BTU

   CREDIT          OFFGAS      CAPITAL          OPERATING COST-OR-CREDIT              NET           NET COST
                    FLOW        COST       FIXED       UTILITIES       RECOVERY   ANNUALIZED     OR SAVINGS(-)
                                           COST                        CREDIT   COST OR CREDIT(-)  PER SCFM
                    SCFM        (000)      (000)         (000)          (000)        (000)          $/SCFM

 0.0000$/1000 SCF
                     300.         58.        17.          32.             0.          49.          163.85
                    1000.        144.        42.         107.             0.         150.          149.54
                    5000.        273.        81.         537.             0.         618.          123.62
                   20000.        594.       179.        2147.             0.        2326.          116.29
                   50000.        955.       293.        5368.             0.        5661.          113.22
                  100000.       1671.       513.        *****             0.       11249.          112.49
 0.0500$/1000 SCF
                     300.         58.        17.          32.             8.          41.          137.57
                    1000.        144.        42.         107.            26.         123.          123.26
                    5000.        273.        81.         537.           131.         487.           97.34
                   20000.        594.       179.        2147.           526.        1800.           90.01
                   50000.        955.       293.        5368.          1314.        4347.           86.94
                  100000.       1671.       513.        *****          2628.        8621.           86.21
 0.1000$/1000 SCF
                     300.         58.        17.          32.            16.          33.          111.29
                    1000.        144.        42.         107.            53.          97.           96.98
                    5000.        273.        81.         537.           263.         355.           71.06
                   20000.        594.       179.        2147.          1051.        1275.           63.73
                   50000.        955.       293.        5368.          2628.        3033.           60.66
                  100000.       1671.       513.        *****          5256.        5993.           59.93
 0.2000$/1000 SCF
                     300.         58.        17.          32.            32.          18.           58.73
                    1000.        144.        42.         107.           105.          44.           44.42
                    5000.        273.        81.         537.           526.          92.           18.50
                   20000.        594.       179.        2147.          2102.         223.           11.17
                   50000.        955.       293.        5368.          5256.         405.            8.10
                  100000.       1671.       513.        *****         10512.         737.            7.37
 0.4000$/1000 SCF
                     300.         58.        17.          32.            63.         -14.          -46.39
                    1000.        144.        42.         107.           210.         -61.          -60.70
                    5000.        273.        81.         537.          1051.        -433.          -86.62
                   20000.        594.       179.        2147.          4205.       -1879.          -93.95
                   50000.        955.       293.        5368.         10512.       -4851.          -97.02
                  100000.       1671.       513.        *****         21024.       -9775.          -97.75
```

REPORT 2

CONTROL DEVICE EVALUATION
CONDENSATION

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Prepared for
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Office of Air Quality Planning and Standards
Environmental Protection Agency
Research Triangle Park, North Carolina

December 1980

D103R

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I. INTRODUCTION

A. GENERAL

Condensation is an operation in which one or more volatile components of a vapor mixture are separated from the remaining vapor by being changed to the liquid phase through extraction of the heat of condensation. In a two-component vapor stream, where one of the components is considered to be noncondensible (e.g., air), condensation occurs when the partial pressure of the condensible component (e.g., VOC) is equal to the component's vapor pressure. To achieve this condition the system pressure may be increased at a given temperature or the temperature of the vapors may be reduced at constant pressure.

Condensation as an emission control method is often used with auxiliary air pollution control equipment.[1*] For example, condensers can be located before (upstream of) absorbers, incinerators, or carbon beds to reduce the VOC load on the more expensive control device, thereby possibly reducing the size and cost of the other control device. The condenser can also remove vapor components that might adversely affect the operation of other equipment or cause corrosion problems or can be used to simply recover valuable material that would otherwise be destroyed. When condensers are used alone, as in gasoline vapor control from bulk terminals, refrigeration is often employed to obtain the low temperatures necessary for acceptable VOC removal efficiencies.

The suitability of condensation for VOC emission control is generally dependent on the following factors: the VOC concentration in the inlet (usually above 1%); the VOC removal efficiency required; the recovery value of the contained VOC; and the condenser size required for handling the gas flow rate.

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[*] See Sect. VII for the references cited in this report.

II. SYSTEM DESCRIPTION

Reproduced from best available copy.

A. GENERAL

When a condenser is used to control emissions, it is usually operated at the constant pressure of the control source, which is normally atmospheric. This report is limited to the evaluation of condensation as a VOC control method at atmospheric pressure.

B. CONDENSATION EQUIPMENT

The two most common types of condensers that operate at atmospheric pressure are surface and contact condensers.

1. Surface Condensers

Most surface condensers are of the shell and tube type shown in Fig. II-1.[2] The coolant ususally flows through the tubes, and the vapors condense on the outside (shell) tube surface. The condensed vapor forms a film on the cool tube and drains away to a collection tank for storage or disposal.

The coolant used depends on the temperature required for condensation. Chilled water, brine, and refigerants are normally used in surface condenser operation. Air-cooled surface condensers are also available and are usually constructed with extended surface fins. When the cool air passes over the finned tubes, the vapors condense inside the tubes.

2. Contact Condensers

In contrast to surface condensers, where the coolant does not contact the vapors or the condensate, contact condensers usually cool the vapor by spraying an ambient-temperature or slightly chilled liquid directly into the gas stream. The coolant is usually water, although in some situations a material used in the process can be used as the coolant. These devices are relatively uncomplicated, as is shown by the typical design in Fig. II-2.[2] Most contact condensers are simple spray chambers that are usually baffled to ensure good contact.

3. Comparison of Surface and Contact Condensers

Both devices have advantages and disadvantages for a given operation. Final selection will usually be based on the following comparative information.

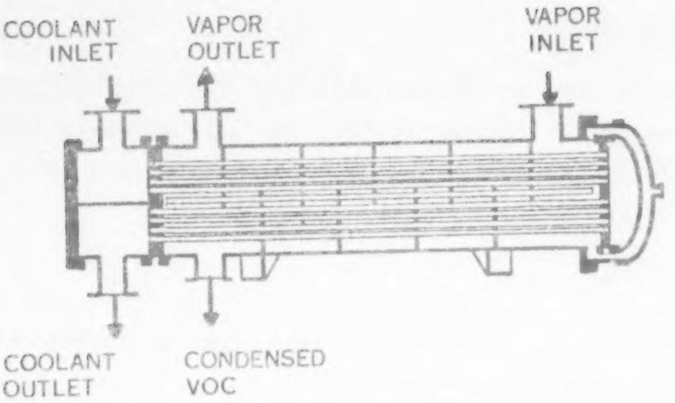
COOLANT
INLET
VAPOR
OUTLET
VAPOR
INLET
COOLANT
OUTLET
CONDENSED
VOC

Fig. II-1. Schematic Diagram of a Shell and Tube Surface Condenser

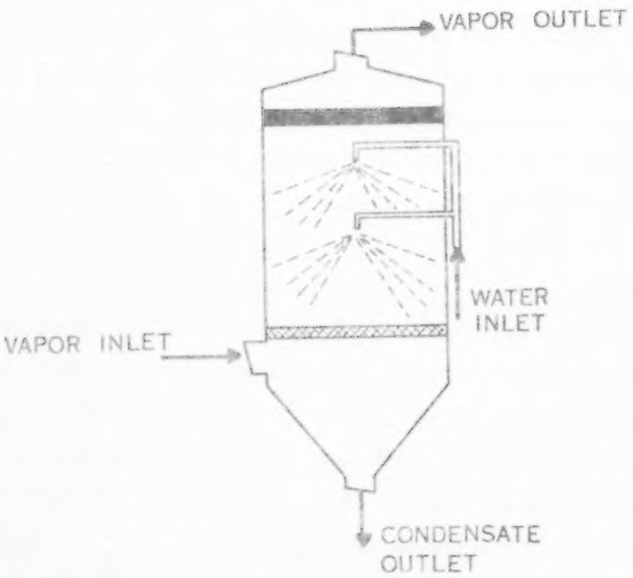
VAPOR OUTLET
WATER
INLET
VAPOR INLET
CONDENSATE
OUTLET

Fig. II-2. Schematic Diagram of a Contact Condenser

1. Contact condensers are more flexible, are more simple in design, and are less expensive to install than surface condensers. They have advantages in corrosive situations, when particulates have to be removed, and when the coolant is the process liquid condensed.
2. Contact condensers can be more efficient than surface condensers in removing VOC from a vent gas stream because they act as an absorber as well as a condenser when the VOC is soluble in the coolant.
3. Spent coolant from contact condensers cannot usually be reused directly and therefore can be a secondary emission source or a wastewater disposal problem.
4. The coolant from surface condensers is not contaminated and normally can be recycled.
5. Surface condensers may be equipped with more auxiliary equipment, such as a refrigeration unit, to supply the coolant and consequently generally require more maintenance than contact condensers.
6. Surface condensers can be used to directly recover valuable and marketable VOC from the gas stream.

Although contact condensers can be highly efficient in removing VOC from a vapor stream, as in vacuum jet service, they can create additional wastewater emission control problems downstream. Unless the VOC-contaminated water discharged from the condenser is treated (e.g., stripped, absorbed, extracted), secondary emissions will result from evaporation. Because of this liability, only surface condensers are evaluated in this report.

4. Condenser System Flow Sheet

Figure II-3 illustrates one of the configurations that can be utilized for a surface condenser as an emission control device. The coolant is supplied to the condenser by a refrigeration unit. Temperatures as low as -80°F may be required in order to obtain the high VOC removal efficiencies needed. The major equipment required for the condenser system includes a shell-and-tube heat exchanger, a coolant supply, a recovery tank for the condensed VOC, and a pump to discharge the recovered VOC to storage or disposal.

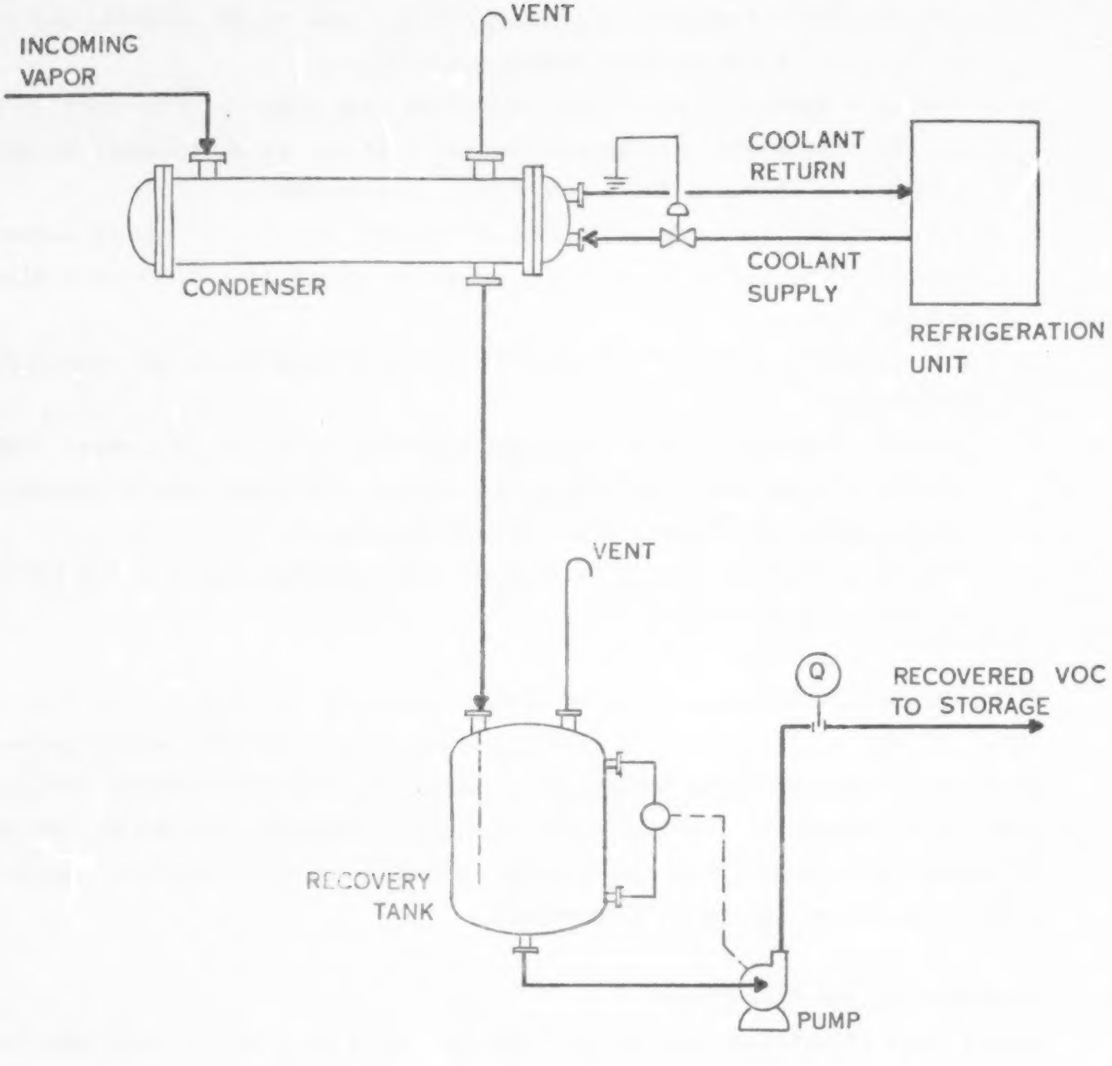
VENT
INCOMING VAPOR
COOLANT RETURN
CONDENSER
COOLANT SUPPLY
REFRIGERATION UNIT
VENT
Q
RECOVERED VOC TO STORAGE
RECOVERY TANK
PUMP

Fig. II-3. Basic Surface Condenser System

III. FACTORS INFLUENCING PERFORMANCE AND MODEL SYSTEMS

A. SYSTEM EFFICIENCIES

The VOC removal efficiency of a condenser system is determined by the amount of reduction in the VOC partial pressure in the gas stream as it passes through the condenser. This is accomplished by reducing the temperature of the gas stream and condensing out some of the VOC.

Any component of any vapor mixture can be recovered (condensed) if brought to equilibrium at a low enough temperature. The temperature necessary to obtain a particular VOC vapor concentration or removal efficiency is dependent on the vapor pressure of the components. When a two-component vapor mixture, in which one of the components is considered to be noncondensible, is to be cooled, condensation will begin when the temperature reached is such that the vapor pressure of the volatile component is equal to its partial pressure. The point at which condensation first occurs is called the dew point. As the vapor is cooled further, condensation continues as long as the partial pressure stays equal to the vapor pressure. The less volatile a compound, that is, the higher the normal boiling point, the smaller the amount that can remain as vapor at a given temperature. Figure III-1[3] shows the vapor pressure dependence on temperatures for selected compounds.

Table III-1[4] gives the estimated temperatures required to reduce the VOC vapor pressures in the gas stream to obtain 50, 80, and 95% removal efficiencies at VOC concentrations of 20, 10, 5, 2, 1, and 0.5 vol % in the gas inlet stream at saturation conditions. The temperature and vapor pressure values represent the pressure and temperature relationships of the aliphatic and halogenated aliphatic hydrocarbon families of the synthetic organic chemicals manufacturing industry and were the basis for condenser and refrigeration system sizing for this report. A temperature of 80°F was selected for the gas stream feed to the condenser.

The calculation methods for a gas stream containing multiple VOCs are complex, particularly when there are significant departures from the ideal behavior of gases and liquids. As a simplification, the temperature necessary for control

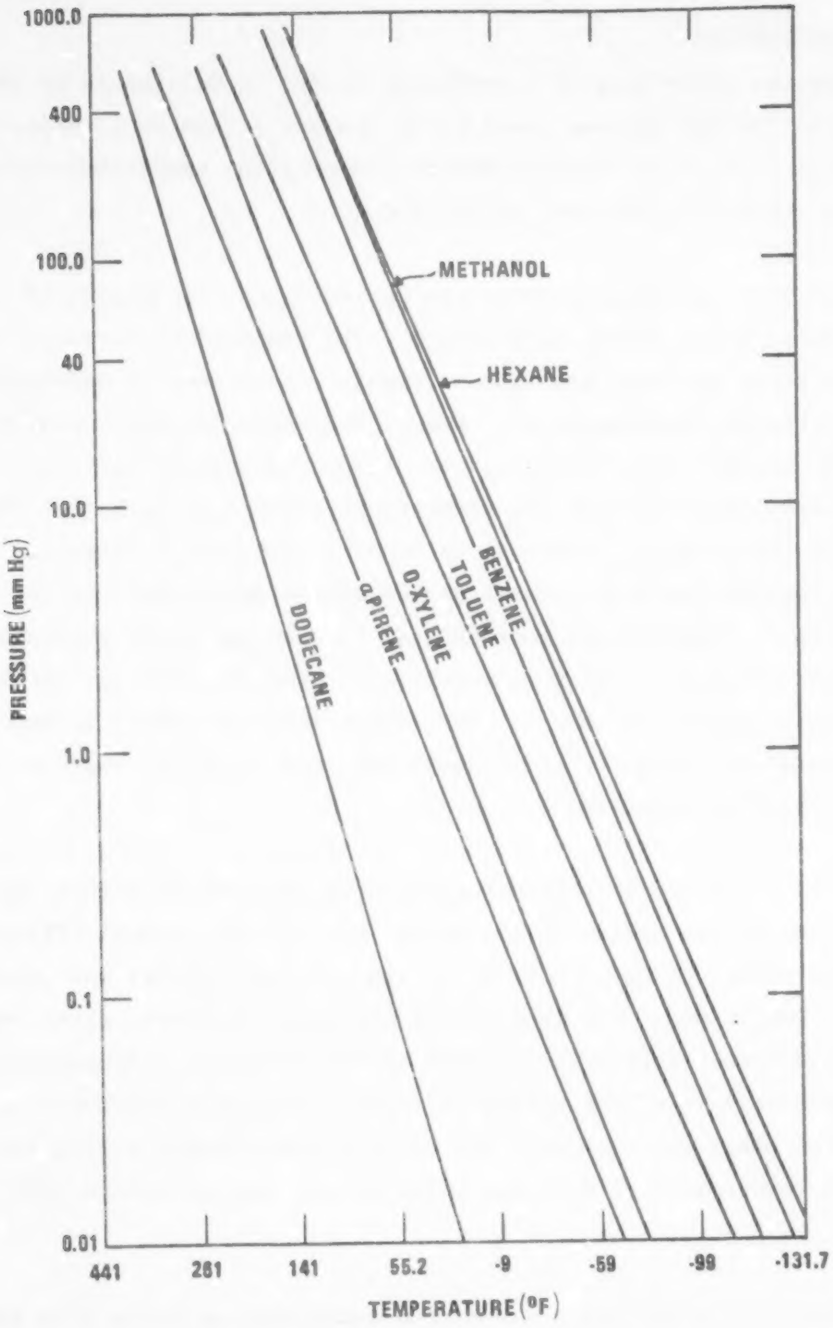

Fig. III-I. Vapor Pressures of Selected Compounds vs Temperature

Table III-1. Parameters for Condenser System Recovery Efficiencies[a,b]

VOC Concentration (vol %)	Vapor Pressure (mm Hg) Required for				Temperature (°F) Required for			
	Feed to Condenser	50% Removal	80% Removal	95% Removal	Feed to Condenser	50% Removal	80% Removal	95% Removal
20	152	76	30.4	7.6	80.0	53.6	24.1	-15.9
10	76	38	15.2	3.8	80.0	55.6	26.2	-11.9
5	38	19	7.6	1.9	80.0	56.7	28.8	-8.0
2	15.2	7.6	3.0	0.8	80.0	57.9	31.5	-2.4
1	7.6	3.8	1.5	0.4	80.0	59.4	33.6	1.8
0.5	3.8	1.9	0.8	0.2	80.0	60.3	36.9	5.0

[a] These vapor pressure and temperature relationships represent the aliphatic hydrocarbon family and were used because they represent an average model compound in the SOCMI.

[b] See ref 4.

by condensation can be roughly approximated by the weighted average of the temperatures necessary for condensation of each condensible VOC in the gas stream at concentrations equal to the total organic concentration.

If water is present in the treated gas stream or if the VOC has a high freezing point (e.g. benzene), normal design practice will require the use of an intermittent heating cycle for removal of ice or frozen hydrocarbons in a continuous system operated at low temperatures. Intermittently operated systems may simply be allowed to heat up, with ambient heat used for de-icing.

B. BASE-CASE MODEL CONDENSER SYSTEM

Condenser design calculations are based on heat transfer that is affected by the overall heat transfer coefficient, on the temperatures of the coolant and the gas stream, and on the surface area. A mathematical solution to the problem is usually achieved by the expression

$$Q = UA \Delta T_m ,$$

where

Q = total heat transferred (Btu/hr),
U = overall heat transfer coefficient [Btu/(hr)(ft^2)(°F)],
A = heat transfer surface area (ft^2),
ΔT_m = mean temperature difference between coolant and gas stream (°F).

In condenser design calculations A is the unknown parameter to be solved for or determined as follows:

$$A = \frac{Q}{U \Delta T_m} .$$

For the base-case design of the condenser and refrigeration systems used in this report the following conditions were assumed:

1. The temperature of the initial gas stream entering the condenser is 80°F, and the stream contains only VOC and air (two components).
2. The gas stream outlet temperatures are those shown in Table III-1 for specific VOC concentrations and removal efficiencies.

3. The air specific heat is 0.24 Btu/(lb)(°F); the VOC specific heat is 0.50 Btu/(lb)(°F); and the VOC latent heat is 200 Btu/lb.
4. The molecular weight of the VOC is 60.
5. The overall heat transfer coefficient is 5.0.
6. The coolant inlet temperature is 10°F less than the gas stream final temperature.
7. The coolant temperature rise through the condenser in all cases is 25°F.
8. The system heat losses, which are dependent on insulation thickness, length of pipe, and ambient temperature, were assumed to be negligible.

The major variables evaluated for the base-case model condenser system in this report are as follows:

1. Flow rates of 100, 500, 1000, and 2000 cfm were selected as representative of the normal or typical range for condenser emission-control-device applications. Flows in excess of 2000 cfm of primarily noncondensible gases require prohibitively large-size condenser systems.
2. Removal efficiencies used were 50, 80, and 95%. An efficiency of 50% can normally be expected when the condenser system is used in conjunction with (usually before) another control device. An efficiency of 80% is an average or typical efficiency reported in the literature[5] and 95% is close to the maximum efficiency reported.[5]
3. VOC concentrations in the gas stream to the condenser at 20, 10, 5, 2, 1, and 0.5% were chosen. High concentrations of 10 and 20% VOC would most likely occur from intermittent operations such as loading or unloading to or from storage facilities. The annual operating time for only these two concentrations was estimated to be just 20% of the total annual operating time.[6] Other VOC concentrations were selected to enable cost comparisions with the other control devices evaluated in similar reports. The application of condensers on streams with less than 0.5% of VOC would be very limited.

IV. DESIGN CONSIDERATIONS

A. GENERAL

The design of an optimum condenser system for a given emission control application is relatively complex. An optimum design requires the selection of a combination of equipment and operating conditions that will satisfy emission control requirements at minimum overall cost. Often a change that reduces the cost of one element (i.e., condenser size) must be balanced against the effect it has on other costs (i.e., refrigeration requirements). Although detailed design procedures are beyond the scope of this report, some of the more significant design considerations and the relationships between them are discussed briefly in this section. For simplicity, these factors are discussed specifically as they apply to a condenser system using a surface condenser with a mechanical refrigeration unit designed to control VOC emissions at various concentrations in air. All design and cost considerations apply to condensation as a method of VOC emission control, and may not be proportionately applicable to condensation used as part of the normal operating process.

B. CAPITAL COST PARAMETERS

1. Condenser

The capital cost of condensers is primarily a function of the total heat transferred and the temperature required. When the heat-transfer coefficients and the required temperature remain relatively constant, the required areas will be approximately proportional to the required heat-transfer rates and to the corresponding flow rates, which in turn are functions of the emission flow rate and the amount of VOC to be condensed.

2. Refrigeration Unit

The capital cost of the refrigeration unit is primarily a function of the heat-transfer rates and the temperatures required. The type of coolant chosen for a refrigeration unit depends on the minimum temperature required: chilled water is normally used for temperatures as low as 40°F; brine is normally used for temperatures of -30°F; and direct-expansion coolants such as Freons are used at temperatures below -30°F.

3. Recovery Tank

The capital cost of the VOC recovery tank primarily depends on the gas stream flow rate and VOC composition.

4. Other Capital Requirements

Most of the other capital items to be considered, including piping, instrumentation, and pumps, are independent of other design considerations.

C. OPERATING COST (CREDIT) PARAMETERS

Certain operating costs are determined by the equipment design for condenser systems, and are briefly discussed.

1. Electrical Power

Electrical power is used mainly for the refrigeration unit that provides coolant to the condenser and for the pumps. The power required for the refrigeration unit is determined by the amount of refrigeration (tons) needed and the coolant temperatures required. These are, in turn, a function of heat transfer rate and temperatures required. Electrical power usage must be considered in arriving at the optimum condenser system design.

The power required for pump operation will be roughly proportional to the gas flow rate through the system and will therefore vary with the concentration and removal efficiencies selected. For the purpose of this evaluation, electrical power requirements for pump operations were considered to be negligible, compared with those for the refrigeration unit.

2. Product Recovery Credits

Product recovery credit is a function of the amount of VOC recovered and its value. The VOC recovered is a function of the emission stream size, the VOC concentration, and the recovery efficiency. The value of the VOC recovered is process specific. In this study values of $0.10/lb and $0.20/lb were assumed as typical product values for the synthetic organic chemicals manufacturing industry.

3. Operating Labor

The only other operating cost of significance is labor. Operating labor is relatively constant regardless of the size of the system, and consists mainly of monitoring the operation of the condenser and refrigeration systems. Operating labor is estimated to be 10% of the total operating time, or 876 hr annually, and probably represents a higher or maximum value.

V. COST AND ENERGY IMPACTS OF CONDENSER SYSTEMS

A. CAPITAL COST ESTIMATES

1. General

The estimated capital costs for a complete condenser system such as that described in Sect. II represent the total investment, including all indirect costs such as engineering and contractors' fees and overheads required for the purchase and installation of all equipment and material to provide a facility as described. These are battery-limit costs and do not include provisions for bringing utilities, services, or roads to the site; backup facilities; land; required research and development; or process piping interconnections that may be required within the process generating the waste gas flow to the condenser system.

The estimated costs are based on a new-plant installation; retrofit costs are not included. Such costs are usually higher than those for a new-site installation for a similar system and include, for example, demolition, crowded construction working conditions, scheduling construction activities with production activities, and longer runs of interconnecting piping. These factors are so site specific that no attempt was made to provide costs. For specific cases rough costs can be obtained by using the new-site cost data and adding additional costs as required for a specific retrofit situation.

Capital cost estimates represent the total installed capital costs for the condenser section and its refrigeration unit (see Appendix A for the breakdown of these costs). These costs are based on IT Enviroscience experience adjusted to a December 1979 basis. In addition to the capital costs a contingency allowance of 30% is included in the overall capital cost estimates.

2. Model Systems

Estimated capital costs for the complete condenser system described in Sect. II are given in Table V-1. The installed capital cost, shown in Figs. V-1 through V-3, were developed for the model system illustrated in Fig. II-3, in which the condenser is a common shell-and-tube type with a mechanical refrigeration system for providing the coolant.

Table V-1. Capital Cost Summary for Complete Condenser Systems

	Capital Cost (10^3 \$) at VOC Concentrations of												Capital Cost (10^3 \$) at VOC Concentrations of											
	20%				10%				5%				2%				1%				0.5%			
	At Gas Flow Rates (cfm) of												At Gas Flow Rates (cfm) of											
Equipment	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
50% VOC removal																								
Condenser section	77.0	195.0	302.0	475.0	59.0	145.0	222.0	342.0	47.0	110.0	165.0	254.0	38.0	85.0	125.0	190.0	35.0	75.0	111.0	170.0	34.0	72.0	105.0	158.0
Refrigeration unit	5.4	18.0	32.0	52.0	3.8	11.5	20.0	32.0	3.8	8.0	13.0	21.0	3.8	5.3	8.7	15.1	3.8	4.1	7.2	12.4	3.8	3.8	6.0	10.2
Total	82.4	213.0	334.0	527.0	62.8	156.5	242.0	374.0	50.8	118.0	178.0	275.0	41.8	90.3	133.7	205.1	38.8	79.1	118.2	182.4	37.8	75.8	111.0	168.2
80% VOC removal																								
Condenser section	70.0	175.0	270.0	420.0	53.0	127.0	192.0	300.0	43.0	98.0	145.0	225.0	36.0	77.0	115.0	171.0	33.0	69.0	102.0	150.0	32.0	64.0	94.0	140.0
Refrigeration unit	10.7	37.0	62.0	107.0	7.0	24.0	38.0	67.0	4.5	15.4	26.2	44.0	4.5	11.7	20.0	34.3	3.8	9.8	17.3	28.3	3.8	8.3	13.6	23.4
Total	80.7	212.0	332.0	527.0	60.0	151.0	230.0	367.0	47.5	113.4	172.2	269.0	40.5	88.7	135.0	205.3	36.8	78.8	119.3	178.3	35.8	72.3	107.6	163.4
95% VOC removal																								
Condenser section	63.0	158.0	240.0	380.0	50.0	118.0	179.0	275.0	41.0	94.0	140.0	215.0	36.0	76.0	112.0	170.0	34.0	70.0	103.0	151.0	32.0	65.0	96.0	145.0
Refrigeration unit	26.0	87.0	145.0	250.0	15.8	57.0	90.0	165.0	11.1	36.5	63.0	107.0	8.7	31.7	49.8	84.8	7.2	22.6	38.1	64.8	6.0	18.9	32.8	56.6
Total	89.0	245.0	385.0	630.0	65.8	175.0	269.0	440.0	52.1	130.4	203.0	322.0	44.7	107.7	161.8	254.8	41.2	92.6	141.1	215.8	38.0	83.9	128.8	201.6

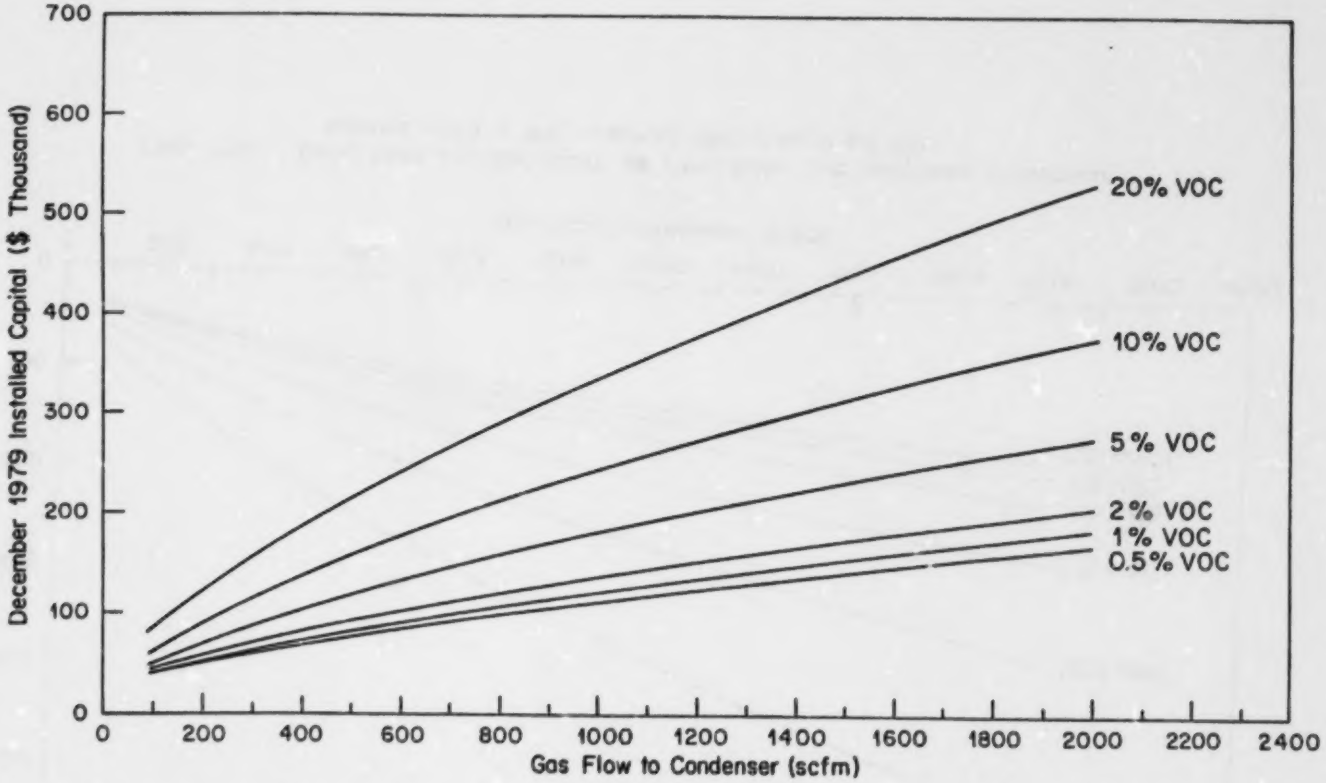

Fig. V-1. Installed Capital Cost vs Flow Rate for Complete Condenser System with a VOC Removal Efficiency of 50%

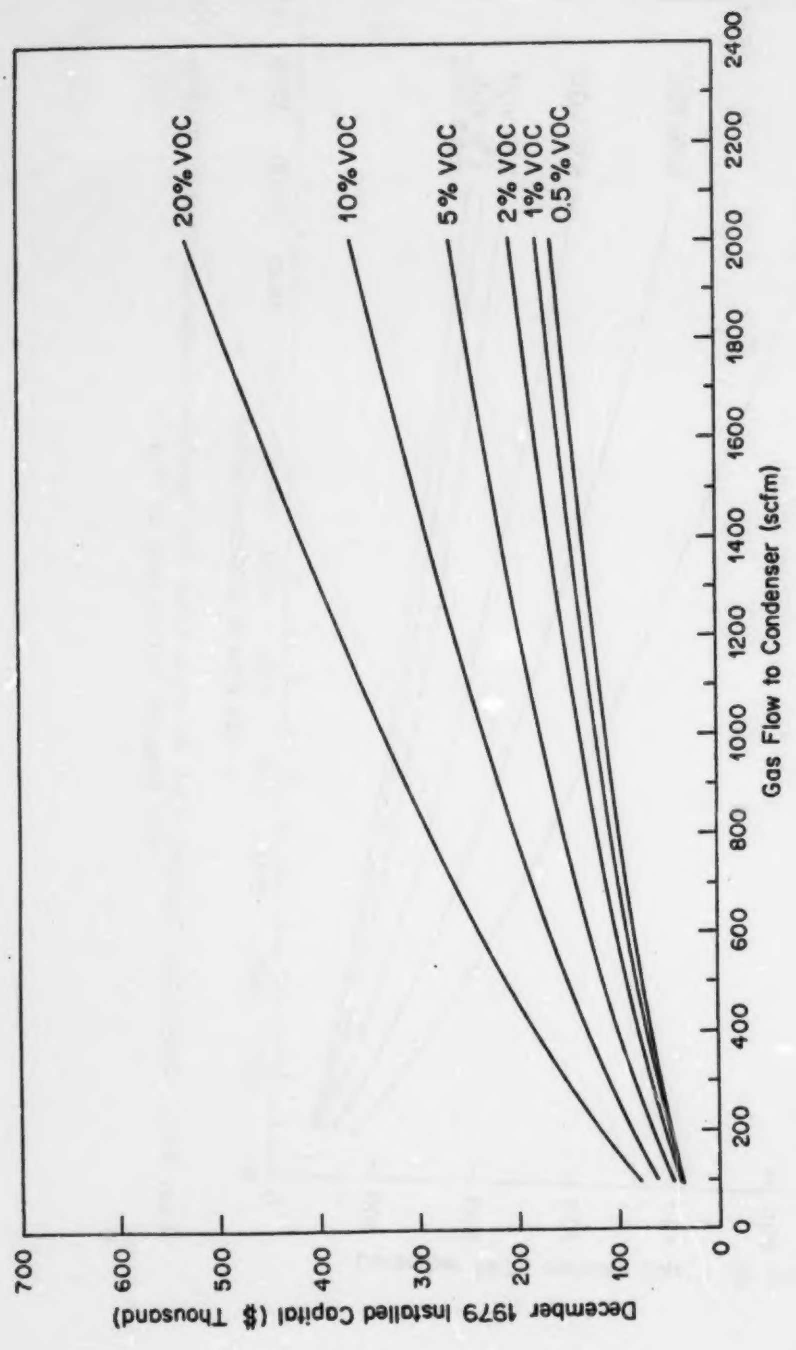

Fig. V-2. Installed Capital Cost vs Flow Rate for Complete Condenser System with a VOC Removal Efficiency of 80%

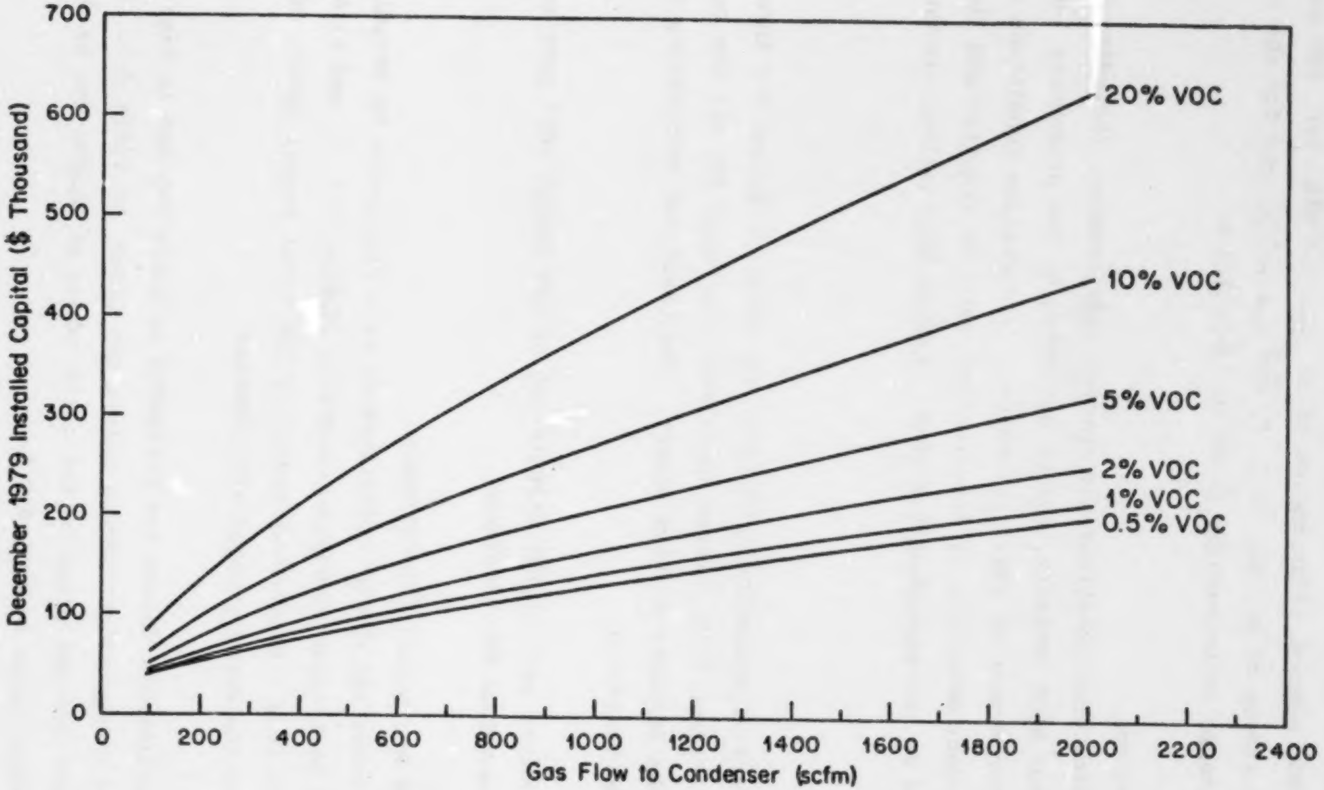

Fig. V-3. Installed Capital Cost vs Flow Rate for Complete Condenser System with a VOC Removal Efficiency of 95%

Costs were developed for the model system for gas flow rates of 100, 500, 1000, and 2000 scfm, for VOC removal efficiencies of 50, 80, and 95%, for VOC concentrations in the gas stream of 20, 10, 5, 2, 1, and 0.5 vol %, and for the temperature—vapor-pressure relationships given in Table III-1.

3. Criteria and Limitations

Costs for other system configurations and special requirements, including corrosive conditions and high humidity, can be estimated by the procedures that were used in the development of these estimates. If corrosive conditions were present, more stringent materials of construction would be required and the capital costs would be correspondingly higher. Sample calculations are shown in Appendix B.

B. ANNUAL COSTS

Annual costs for various operating conditions are given in Tables V-2 through V-4 and Figs. V-4 through V-10. These costs were the basis for all the cost-effectiveness graphs included in this report. The basis for calculating annual costs is defined in Table V-5.

Product recovery values used in the calculation of net annual cost were zero, 10¢, and 20¢ per pound of VOC recovered.

C. COST EFFECTIVENESS AND ENERGY EFFECTIVENESS

The cost effectiveness and energy effectiveness were calculated by dividing the annual cost for a particular operating condition (Tables V-2, 3, and 4) or energy consumption (e.g., electrical power) by the total annual amount of VOC recovered with the indicated removal efficiencies.

Typical cost-effectiveness values are presented in Table V-6 and in Figs. V-11 through V-16, and energy effectiveness values are given in Table V-7. Values for conditions that are not given in the cited tables or graphs can be determined by the methods given in Appendix B.

Table V-2. Annual Cost Summary for 50% VOC Removal

	Annual Cost (10^3 \$) at VOC Concentrations of											
	20%[a]				10%[a]				5%			
	At Gas Flow Rates (cfm) of											
	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
Fixed costs (29% of capital)	23.9	61.8	96.9	152.8	18.2	45.4	70.2	108.5	14.7	34.2	51.6	79.8
Electricity ($0.03/kWh)	0.1	0.5	1.0	2.0	0.1	0.3	0.5	1.1	0.2	0.8	1.6	3.2
Labor ($15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost	37.1	75.4	111.0	167.9	31.4	58.8	83.8	122.7	28.0	48.1	66.3	96.1
VOC recovery credit												
@ $0.10/lb	16.6	83.2	166.4	332.9	8.3	41.6	83.2	166.4	20.8	104.0	208.1	416.1
@$0.20/lb	33.3	166.4	332.9	665.8	16.6	83.2	166.4	332.9	41.6	208.1	416.1	832.2
Net annual cost (credit)												
@ $0.10/lb	20.5	(7.8)	(55.4)	(165.0)	23.1	17.2	0.6	(43.7)	7.2	(55.9)	(141.8)	(320.0)
@ $0.20/lb	3.8	(91.0)	(211.9)	(497.9)	14.8	(24.4)	(82.6)	(209.2)	(13.6)	(160.0)	(349.8)	(736.1)

	Annual Cost (10^3 \$) at VOC Concentrations of											
	2%				1%				0.5%			
	At Gas Flow Rates (cfm) of											
	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
Fixed costs (29% of capital)	12.1	26.2	38.8	59.5	11.3	22.9	34.3	52.9	11.0	22.0	32.2	48.8
Electricity ($0.03/kWh)	0.1	0.5	0.9	1.8	0.1	0.3	0.6	1.3	0.1	0.3	0.6	1.1
Labor ($15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost	25.2	39.8	52.8	74.4	24.4	36.3	48.0	67.3	24.1	35.4	45.9	63.0
VOC recovery credit												
@ $0.10/lb	8.3	41.6	83.2	166.4	4.2	20.8	41.6	83.2	2.1	10.4	20.8	41.6
@ $0.20/lb	16.6	83.2	166.4	332.9	8.3	41.6	83.2	166.4	4.2	20.8	41.6	83.2
Net annual cost (credit)												
@ $0.10/lb	16.9	(1.8)	(30.4)	(92.0)	20.2	15.5	6.4	(15.9)	22.0	25.0	25.1	21.4
@ $0.20/lb	8.6	(43.4)	(113.6)	(258.5)	16.1	(5.3)	(35.2)	(99.1)	19.9	14.6	4.3	(20.2)

[a] Based on 1752-hr/yr operation.

Table V-3. Annual Cost Summary for 80% VOC Removal

	Annual Cost (10^3 \$) at VOC Concentrations of											
	20%[a]				10%[a]				5%			
	At Gas Flow Rates (cfm) of											
	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
Fixed costs (29% of capital)	23.4	61.5	96.3	152.8	17.4	43.8	66.7	106.4	13.8	32.9	49.9	78.0
Electricity (\$0.03/kWh)	0.2	1.1	2.2	4.5	0.1	0.6	1.3	2.5	0.4	2.0	3.9	7.8
Labor (\$15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost	36.7	75.7	111.6	170.4	30.6	57.5	81.1	122.0	27.3	48.0	66.9	98.9
VOC recovery credit												
@ \$0.10/lb	26.6	133.2	266.3	532.6	13.3	66.6	133.2	266.3	33.3	166.4	332.9	665.8
@ \$0.20/lb	53.3	266.3	532.6	1065.2	26.6	133.2	266.3	532.6	66.6	332.9	665.8	1331.6
Net annual cost (credit)												
@ \$0.10/lb	10.1	(57.5)	(154.7)	(362.2)	17.3	(9.1)	(52.1)	(144.3)	(6.0)	(118.4)	(266.0)	(566.9)
@ \$0.20/lb	(16.6)	(190.6)	(421.0)	(894.8)	4.0	(75.7)	(185.2)	(410.6)	(39.3)	(284.9)	(598.9)	(1232.7)

	Annual Cost (10^3 \$) at VOC Concentrations of											
	2%				1%				0.5%			
	At Gas Flow Rates (cfm) of											
	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
Fixed costs (29% of capital)	11.7	25.7	39.2	59.5	10.7	22.9	34.6	51.7	10.4	21.0	31.2	47.4
Electricity (\$0.03/kWh)	0.2	1.2	2.4	4.8	0.1	1.0	1.9	3.5	0.2	0.8	1.5	3.1
Labor (\$15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost	25.0	40.0	54.7	77.4	23.9	37.0	48.9	68.6	23.7	34.9	45.8	63.6
VOC recovery credit												
@ \$0.10/lb	13.3	66.6	133.2	266.3	6.7	33.3	66.6	133.2	3.3	16.6	33.3	66.6
@ \$0.20/lb	26.6	133.2	266.3	532.6	13.4	66.6	133.2	266.3	6.6	33.3	66.6	133.2
Net annual cost (credit)												
@ \$0.10/lb	11.7	(26.6)	(78.5)	(188.9)	17.2	3.7	(17.7)	(64.6)	20.4	18.3	12.5	(3.0)
@ \$0.20/lb	(1.6)	(93.2)	(211.6)	(455.2)	10.5	(29.6)	(84.3)	(197.7)	17.1	1.6	(20.8)	(69.6)

Table V-4. Annual Cost Summary for 95% VOC Removal

	Annual Cost (10^3 \$) at VOC Concentrations of											
	20%[a]				10%[a]				5%			
	At Gas Flow Rates (cfm) of											
	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
Fixed costs (29% of capital)	25.8	71.1	111.7	182.7	19.1	50.8	78.0	127.6	15.1	37.8	58.9	93.4
Electricity (\$0.03/kWh)	0.5	2.7	5.4	10.8	0.3	1.6	3.2	6.4	1.0	5.1	10.2	20.5
Labor (\$15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost	39.4	86.9	130.2	206.6	32.5	65.5	94.3	147.1	29.2	56.0	82.2	127.0
VOC recovery credit												
@ \$0.10/lb	31.6	158.1	316.2	632.5	15.8	79.1	158.1	316.2	39.5	197.6	395.3	790.6
@ \$0.20/lb	63.1	316.2	632.5	1265.0	31.6	158.1	316.2	632.4	79.1	395.3	790.6	1581.2
Net annual cost (credit)												
@ \$0.10/lb	7.8	(71.2)	(186.0)	(425.9)	16.7	(13.6)	(63.8)	(169.1)	(10.3)	(141.6)	(313.1)	(663.6)
@ \$0.20/lb	(23.9)	(229.3)	(502.3)	(1058.4)	0.9	(92.6)	(221.9)	(485.3)	(49.9)	(339.3)	(708.4)	(1454.2)

	Annual Cost (10^3 \$) at VOC Concentrations of											
	2%				1%				0.5%			
	At Gas Flow Rates (cfm) of											
	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
Fixed costs (29% of capital)	13.0	31.2	46.9	73.9	11.9	26.8	40.9	62.6	11.0	24.3	37.4	58.5
Electricity (\$0.03/kWh)	0.7	3.4	6.7	13.4	0.5	2.7	5.4	10.7	0.5	2.4	4.7	9.4
Labor (\$15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost	26.8	47.7	66.7	100.4	25.5	42.6	59.4	86.4	24.6	39.8	55.2	81.0
VOC recovery credit												
@ \$0.10/lb	15.8	79.1	158.1	316.2	7.9	39.5	79.1	158.1	4.0	19.8	39.5	79.1
@ \$0.20/lb	31.6	158.1	316.2	632.4	15.8	79.1	158.1	316.2	7.9	39.5	79.1	158.1
Net annual cost (credit)												
@ \$0.10/lb	11.0	(31.4)	(91.4)	(215.9)	17.6	3.1	(19.7)	(71.7)	20.6	20.0	15.7	1.9
@ \$0.20/lb	(4.8)	(110.4)	(249.5)	(532.0)	9.7	(36.5)	(98.7)	(229.8)	16.7	0.3	(23.9)	(77.1)

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[a] Based on 1752-hr/yr operation.

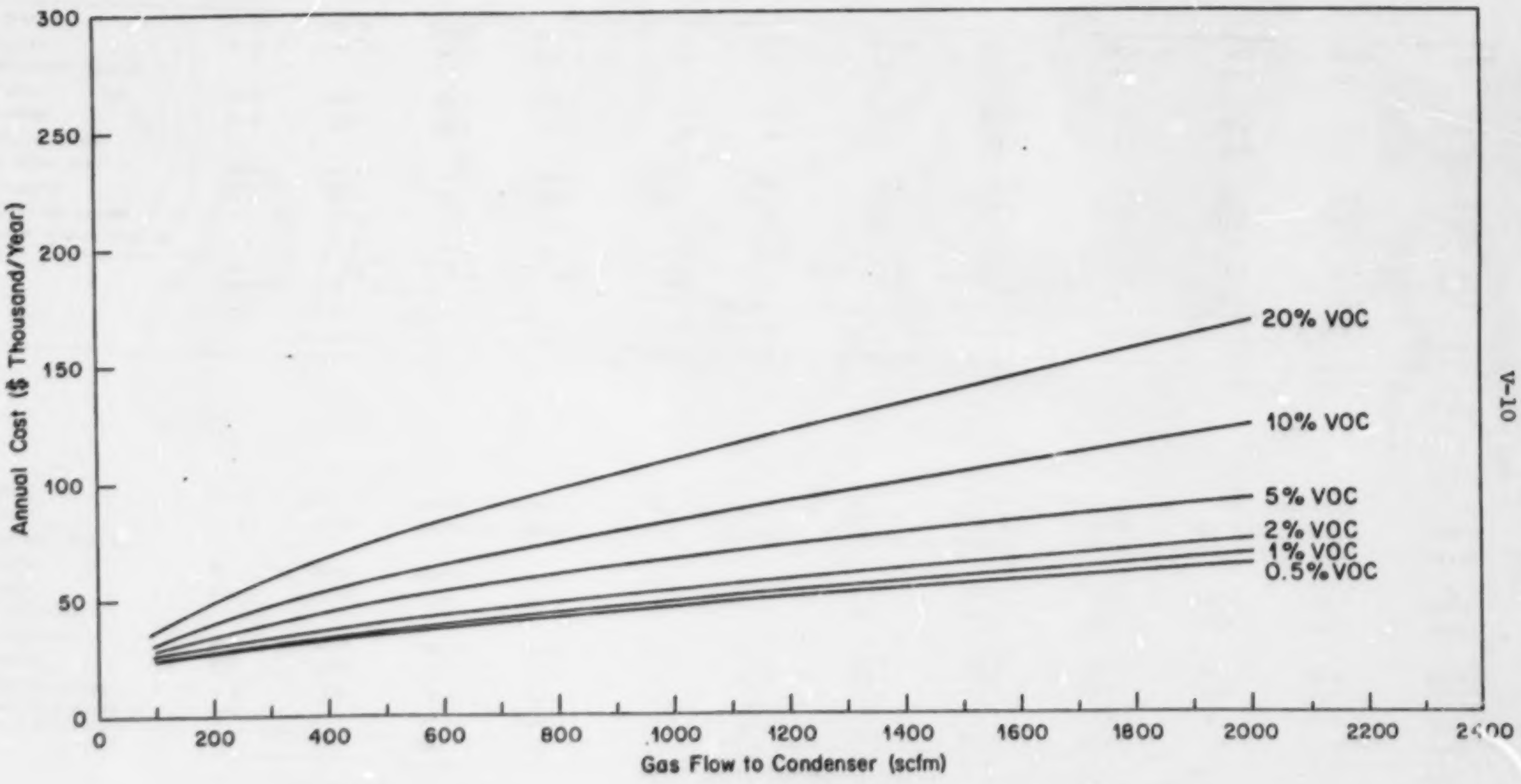

Fig. V-4. Annual Cost vs Flow Rate for Complete Condenser System with VOC Recovery Efficiency of 50% and No VOC Recovery Credit

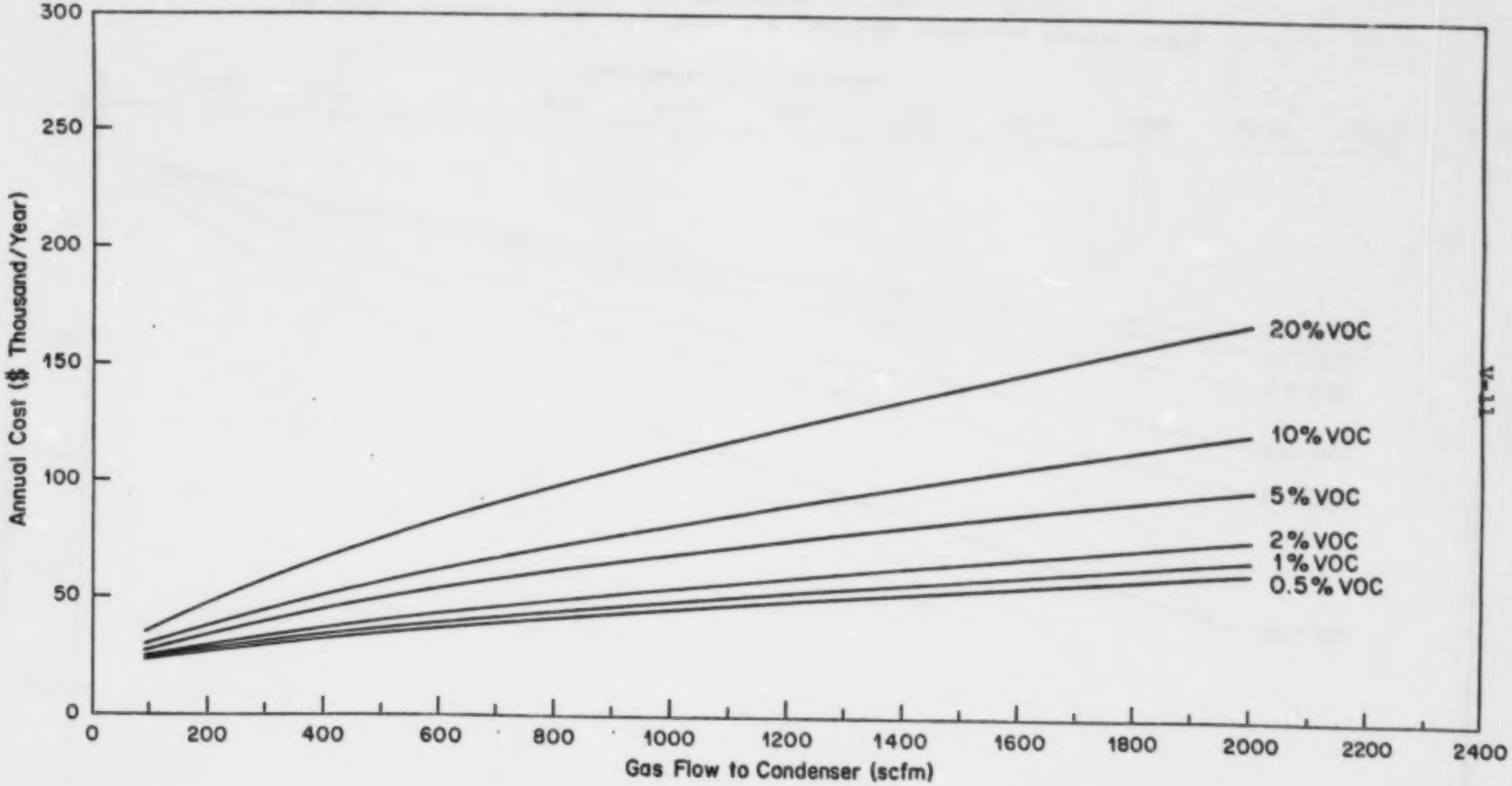

Fig. V-5. Annual Cost vs Flow Rate for Complete Condenser System with VOC Removal Efficiency of 80% and No VOC Recovery Credit

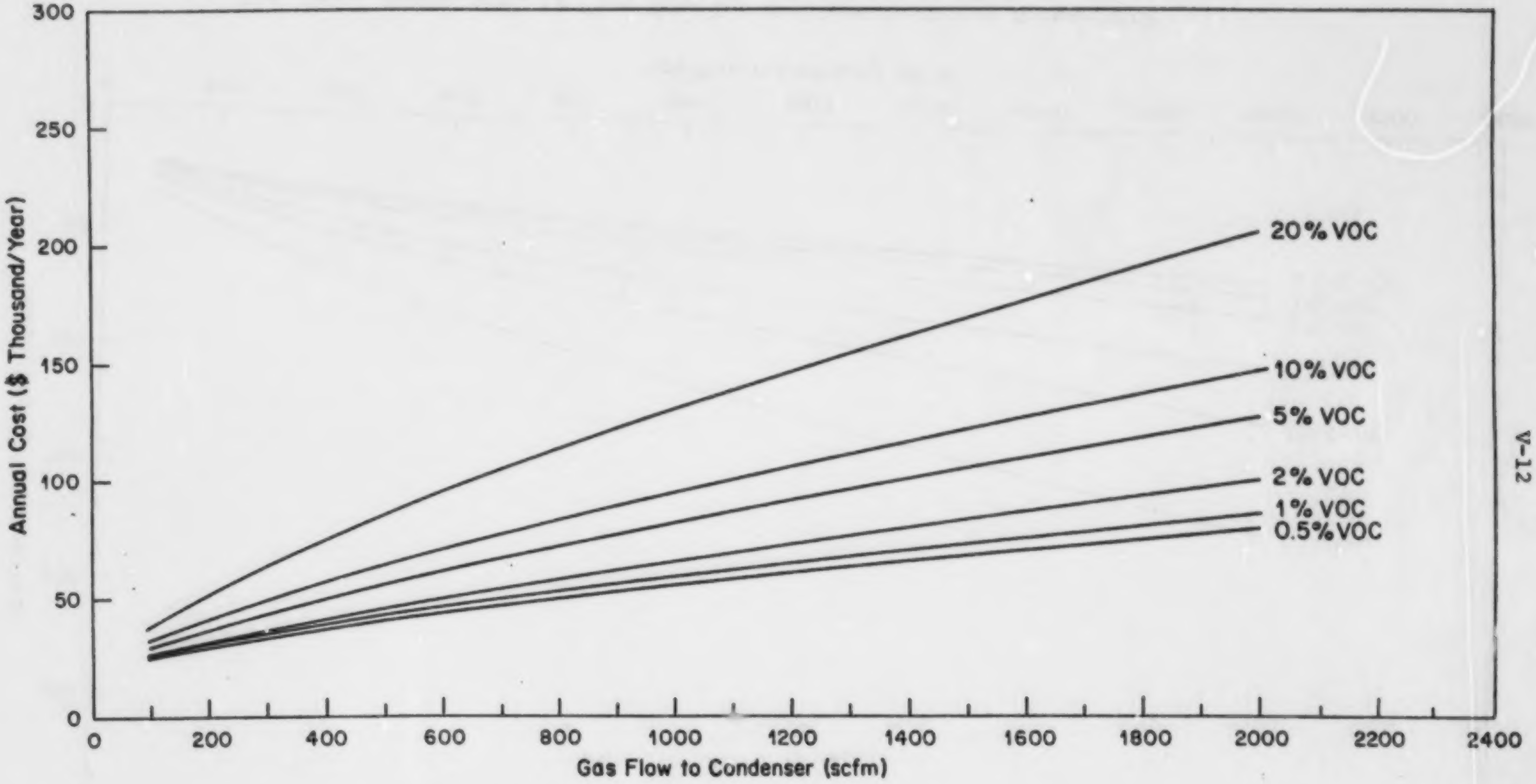

Fig. V-6. Annual Cost vs Flow Rate for Complete Condenser System with VOC Removal Efficiency of 95% and No VOC Recovery Credit

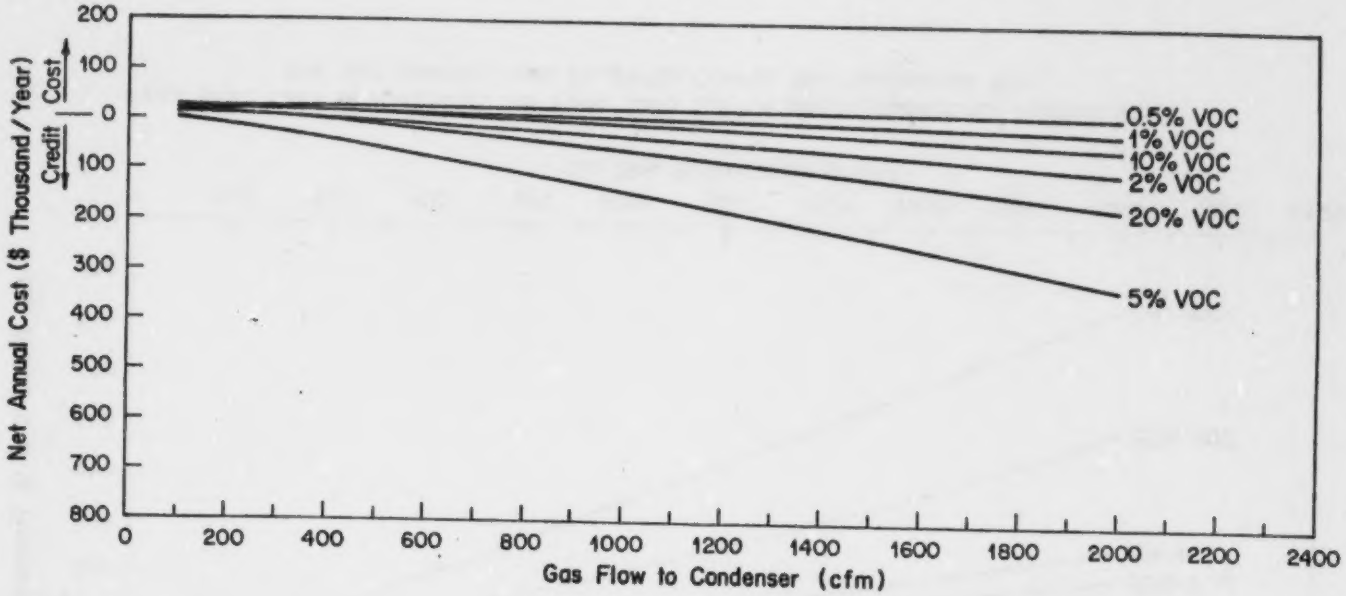

Fig. V-7. Net Annual Cost vs Flow Rate for Complete Condenser System with 50% VOC Removal and $0.10/lb Credit for Recovered VOC

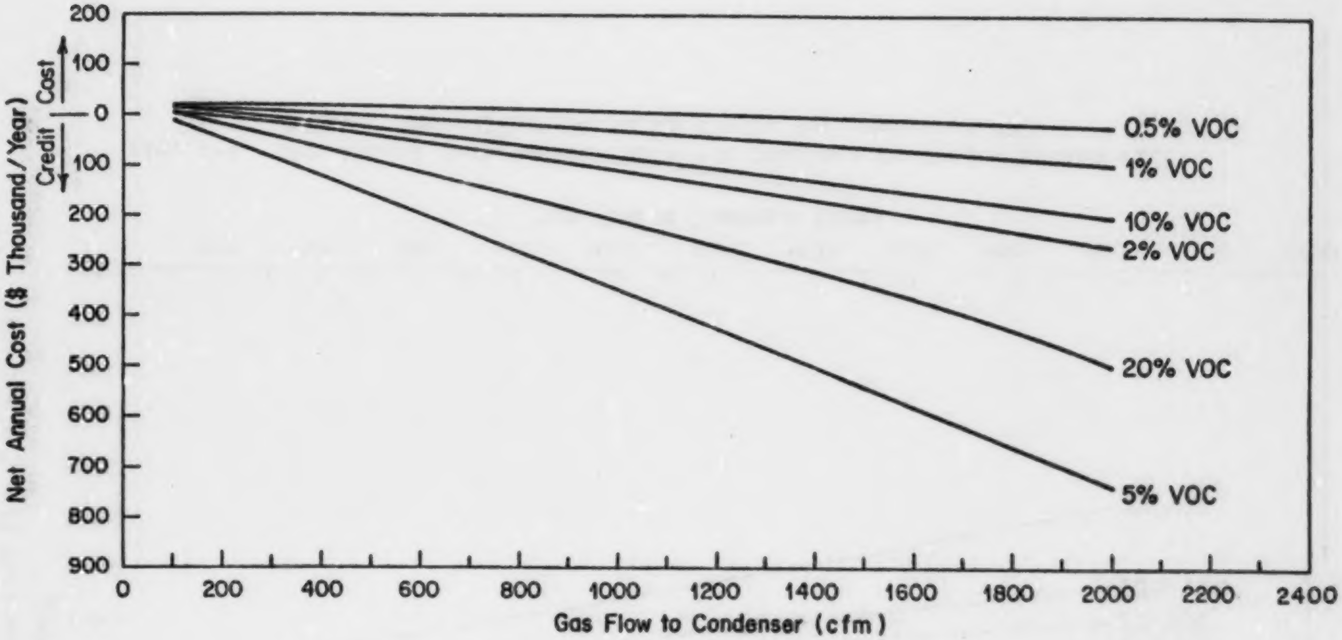

Fig. V-8. Net Annual Cost vs Flow Rate for Complete Condenser System with 50% VOC Removal and $0.20/lb Credit for Recovered VOC

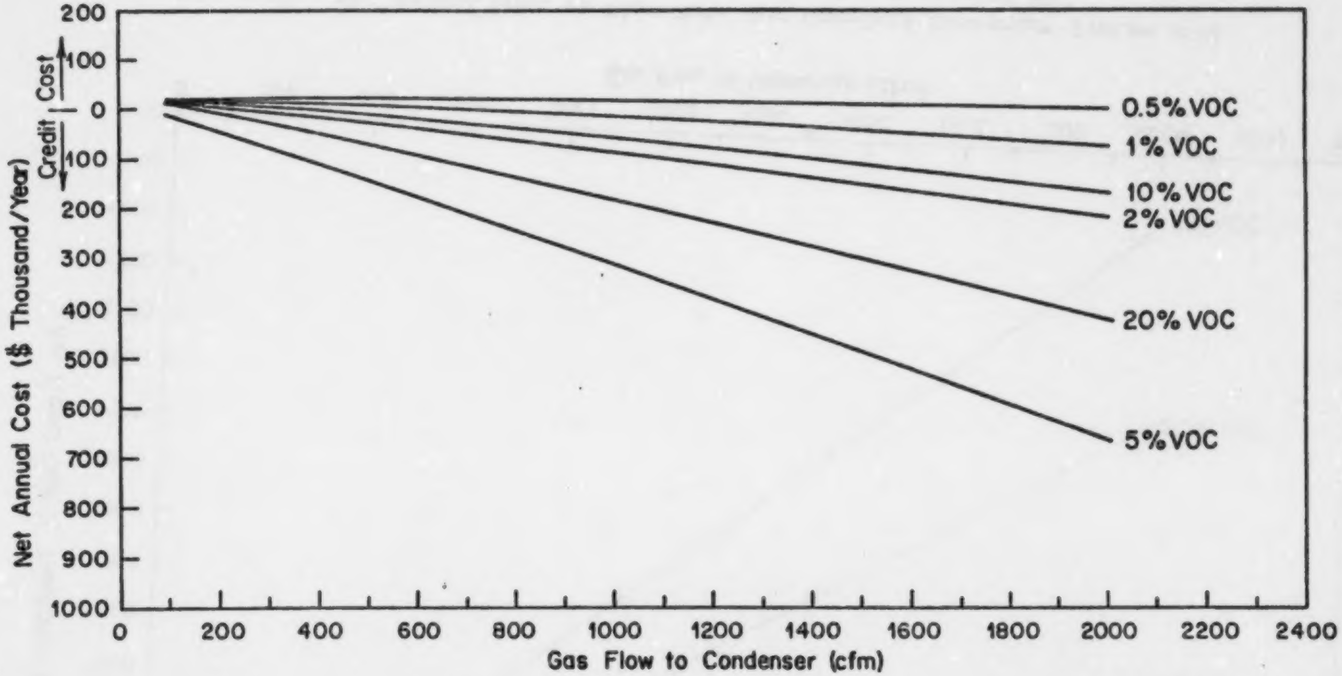

Fig. V-9. Net Annual Cost vs Flow Rate for Complete Condenser System with 95% VOC Removal and $0.10/lb Credit for Recovered VOC

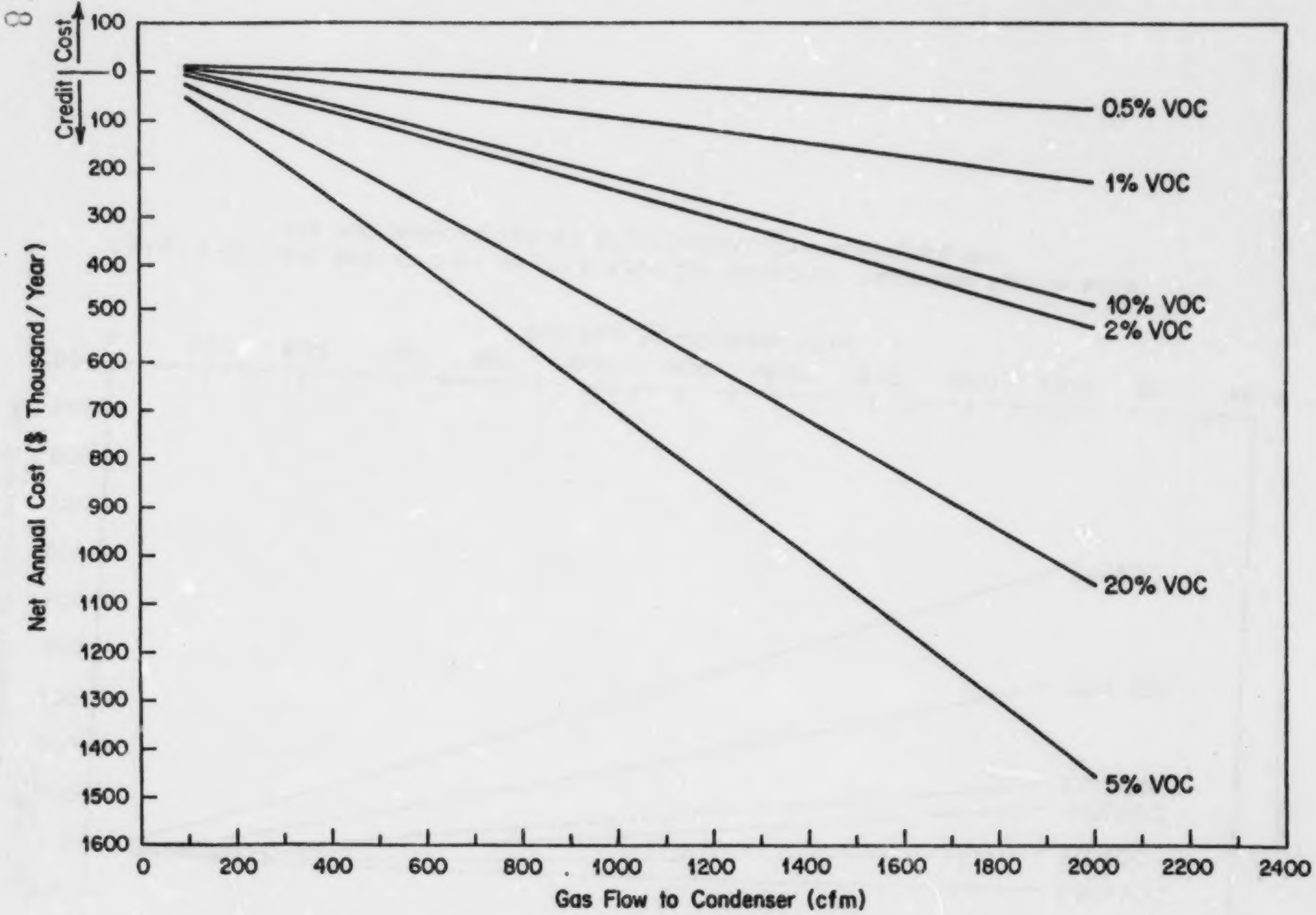

Fig. V-10. Net Annual Cost vs Flow Rate for Complete Condenser System with 95% VOC Removal and $0.20/lb Credit for Recovered VOC

Table V-5. Annual Cost Parameters

Operating factor for 0.5, 1.0, 2.0 and 5.0% VOC streams	8760 hr/yr[a]
Operating factor for 10.0 and 20.0% VOC streams	1752 hr/yr[b]
Operating labor	$15/man-hour
Fixed costs	
Maintenance labor plus materials, 6%	29% installed capital
Capital recovery 18%[c]	
Taxes, insurance, administrative charges, 5%	
Utilities	
Electric power	$0.03/kWh

[a] Process downtime is normally expected to range from 5 to 15%. If the hourly rate remains constant, the annual production and annual VOC emissions will be correspondingly reduced. Control devices will usually operate on the same cycle as the process. From the standpoint of cost-effectiveness calculations the error introduced by assuming continuous operation is negligible.

[b] High concentrations of VOC, i.e., 10 and 20%, would most likely occur from intermittent operations such as loading and unloading into and from storage facilities. Total annual operating time for these operating conditions was estimated to be 20% of the year, or 1752 hr.

[c] Based on 10-year life and 12% interest.

Table V-6. Cost-Effectiveness Summary

VOC Recovery Credit	Cost Effectiveness ($/lb) of VOC Removed at VOC Concentrations of											
	20%[a]				10%[a]				5%			
	At Gas Flow Rates (cfm) of											
	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
@ 95 % recovery												
No credit	0.125	0.055	0.041	0.032	0.206	0.083	0.060	0.047	0.074	0.028	0.021	0.016
$0.10/lb	0.025	(0.045)	(0.059)	(0.067)	0.106	(0.017)	(0.040)	(0.053)	(0.026)	(0.072)	(0.079)	(0.084)
$0.20/lb	(0.076)	(0.145)	(0.159)	(0.167)	0.006	(0.117)	(0.140)	(0.153)	(0.126)	(0.172)	(0.179)	(0.184)
@ 80% recovery												
No credit	0.138	0.057	0.042	0.032	0.230	0.086	0.061	0.046	0.082	0.029	0.020	0.015
$0.10/lb	0.038	(0.043)	(0.058)	(0.068)	0.130	(0.014)	(0.039)	(0.054)	(0.018)	(0.071)	(0.080)	(0.085)
$0.20/lb	(0.062)	(0.143)	(0.158)	(0.168)	0.030	(0.114)	(0.139)	(0.154)	(0.118)	(0.171)	(0.180)	(0.185)
@ 50% recovery												
No credit	0.223	0.091	0.067	0.050	0.377	0.141	0.101	0.074	0.135	0.046	0.032	0.023
$0.10/lb	0.123	(0.009)	(0.033)	(0.050)	0.278	0.041	0.001	(0.026)	0.035	(0.054)	(0.068)	(0.077)
$0.20/lb	0.023	(0.109)	(0.127)	(0.150)	0.178	(0.059)	(0.099)	(0.120)	(0.065)	(0.154)	(0.168)	(0.177)

VOC Recovery Credit	Cost Effectiveness ($/lb) of VOC Removed at VOC Concentrations of											
	2%				1%				0.5%			
	At Gas Flow Rates (cfm) of											
	100	500	1000	2000	100	500	1000	2000	100	500	1000	2000
@ 95% recovery												
No credit	0.169	0.060	0.042	0.032	0.322	0.108	0.075	0.055	0.622	0.201	0.140	0.102
$0.10/lb	0.070	(0.040)	(0.058)	(0.068)	0.223	0.008	(0.025)	(0.045)	0.521	0.101	0.040	0.002
$0.20/lb	(0.030)	(0.140)	(0.158)	(0.168)	0.123	(0.092)	(0.125)	(0.145)	0.422	(0.002)	(0.060)	(0.098)
@ 80% recovery												
No credit	0.188	0.060	0.041	0.029	0.359	0.111	0.073	0.052	0.712	0.210	0.138	0.096
$0.10/lb	0.088	(0.040)	(0.059)	(0.071)	0.258	0.011	(0.027)	(0.049)	0.613	0.110	0.038	(0.005)
$0.20/lb	(0.012)	(0.140)	(0.159)	(0.171)	0.158	(0.089)	(0.127)	(0.148)	0.514	0.010	(0.062)	(0.105)
@ 50% recovery												
No credit	0.303	0.096	0.063	0.045	0.586	0.174	0.115	0.081	1.158	0.340	0.221	0.151
$0.10/lb	0.203	(0.004)	(0.037)	(0.055)	0.485	0.075	0.015	(0.019)	1.057	0.240	0.121	0.051
$0.20/lb	0.103	(0.104)	(0.137)	(0.155)	0.387	(0.025)	(0.085)	(0.119)	0.957	0.140	0.021	(0.049)

[a] Based on 1752-hr/yr operation.

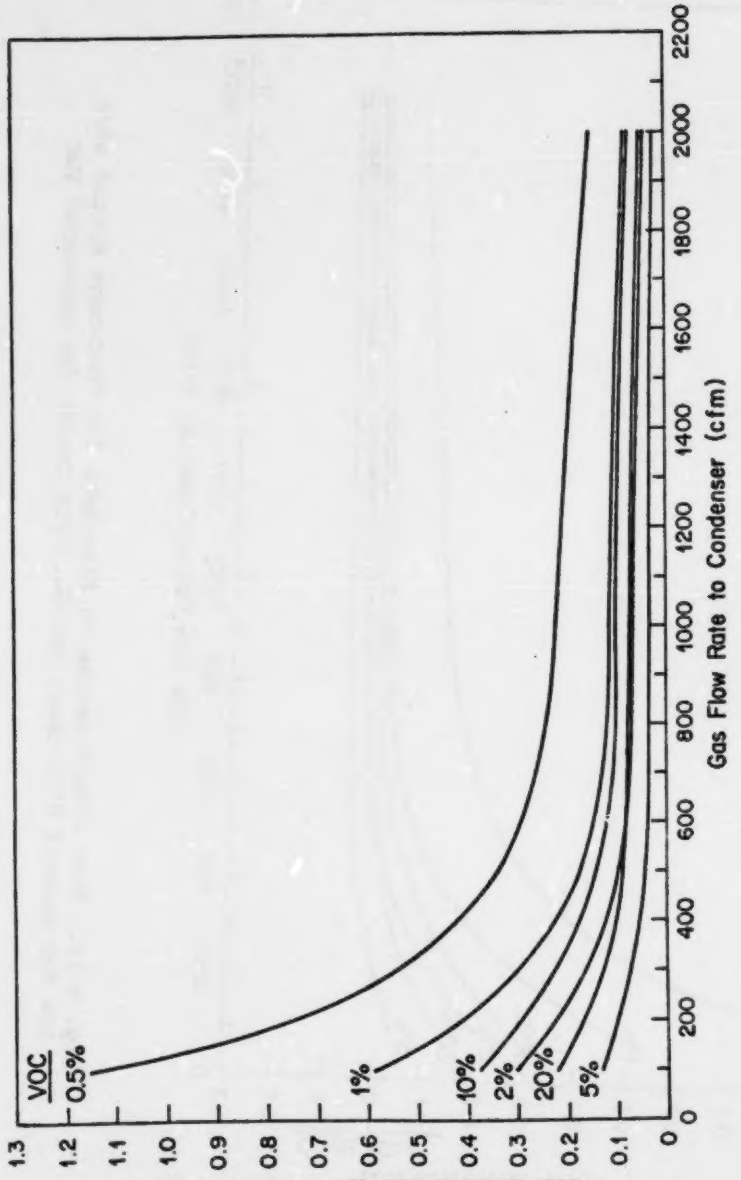

Fig. V-11. Cost Effectiveness vs Flow Rate for Condenser System with 50% VOC Removal Efficiency and No VOC Recovery Credit

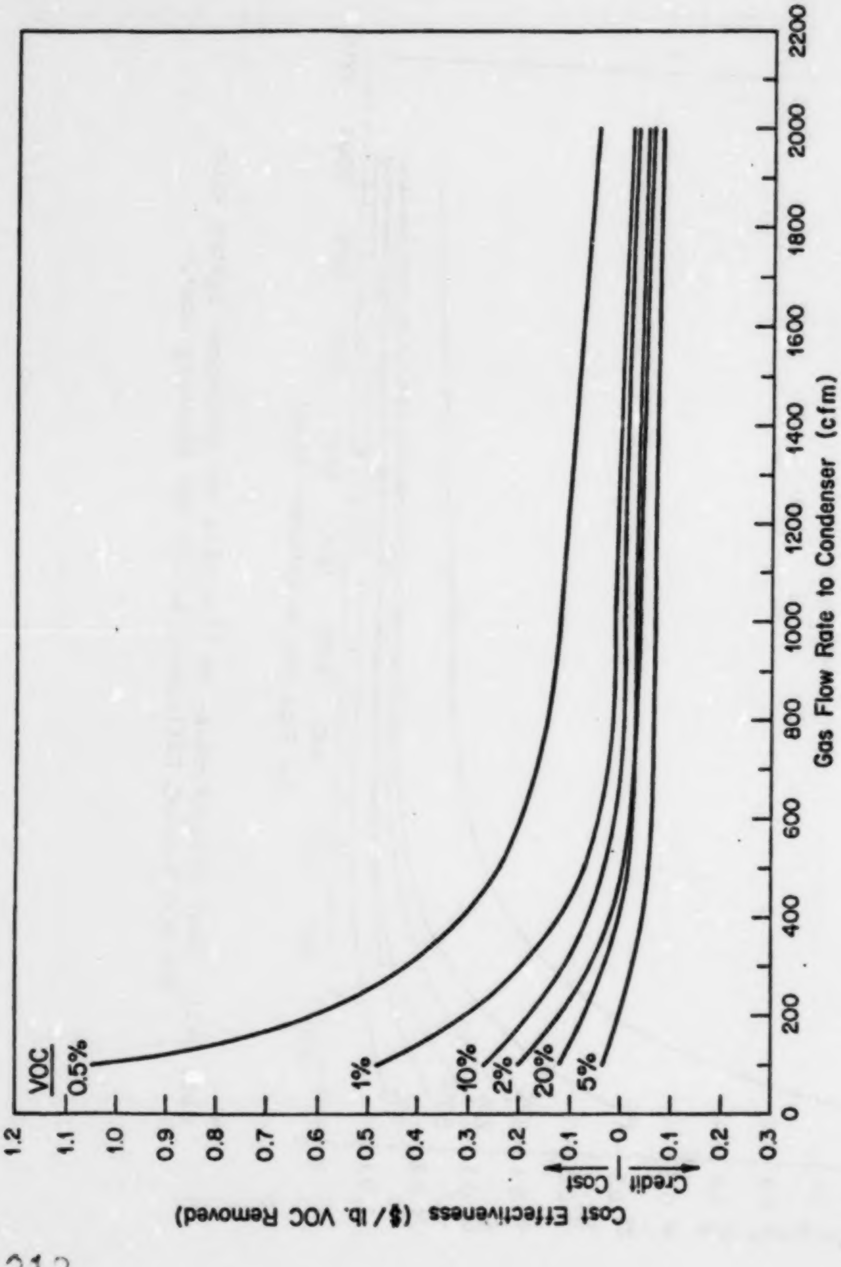

Fig. V-12. Cost Effectiveness vs Flow Rate for Condenser System with 50% VOC Removal Efficiency and $0.10/lb Credit for Recovered VOC

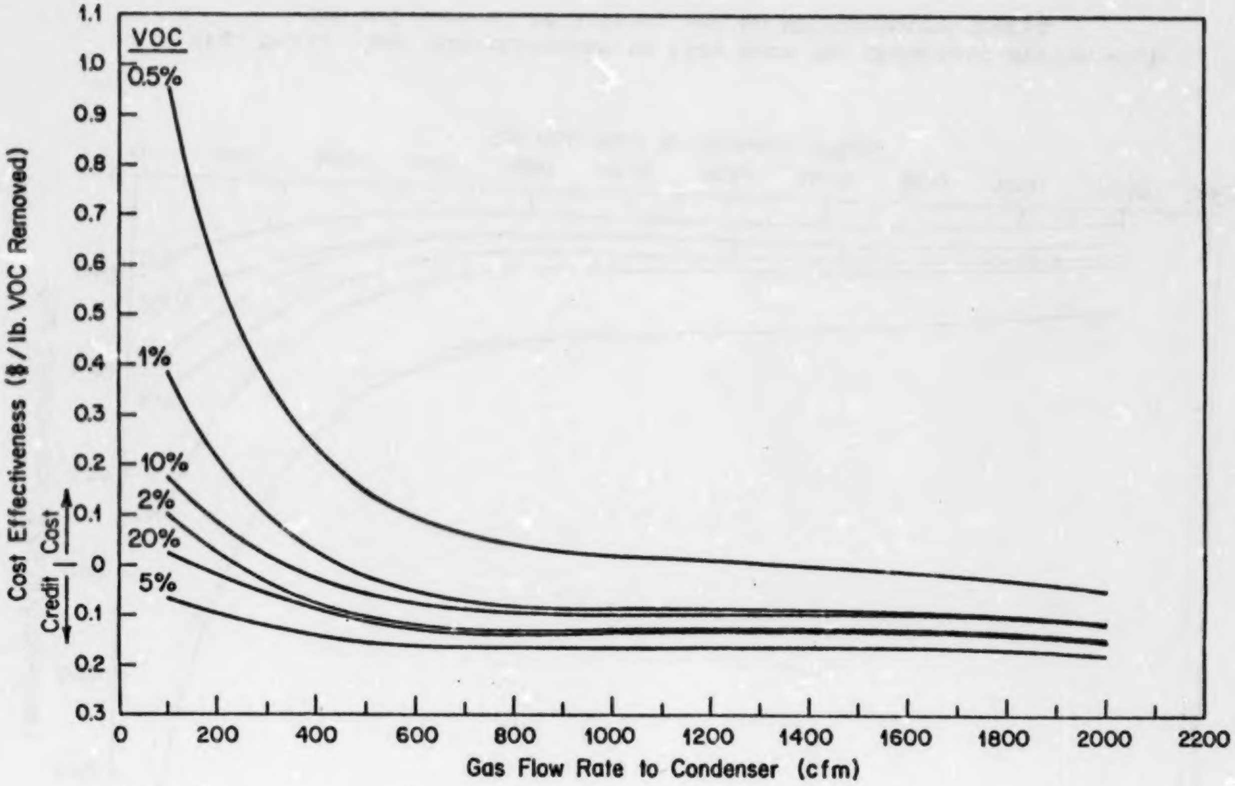

Fig. V-13. Cost Effectiveness vs Flow Rate for Condenser System with 50% VOC Removal Efficiency and $0.20/lb Credit for Recovered VOC

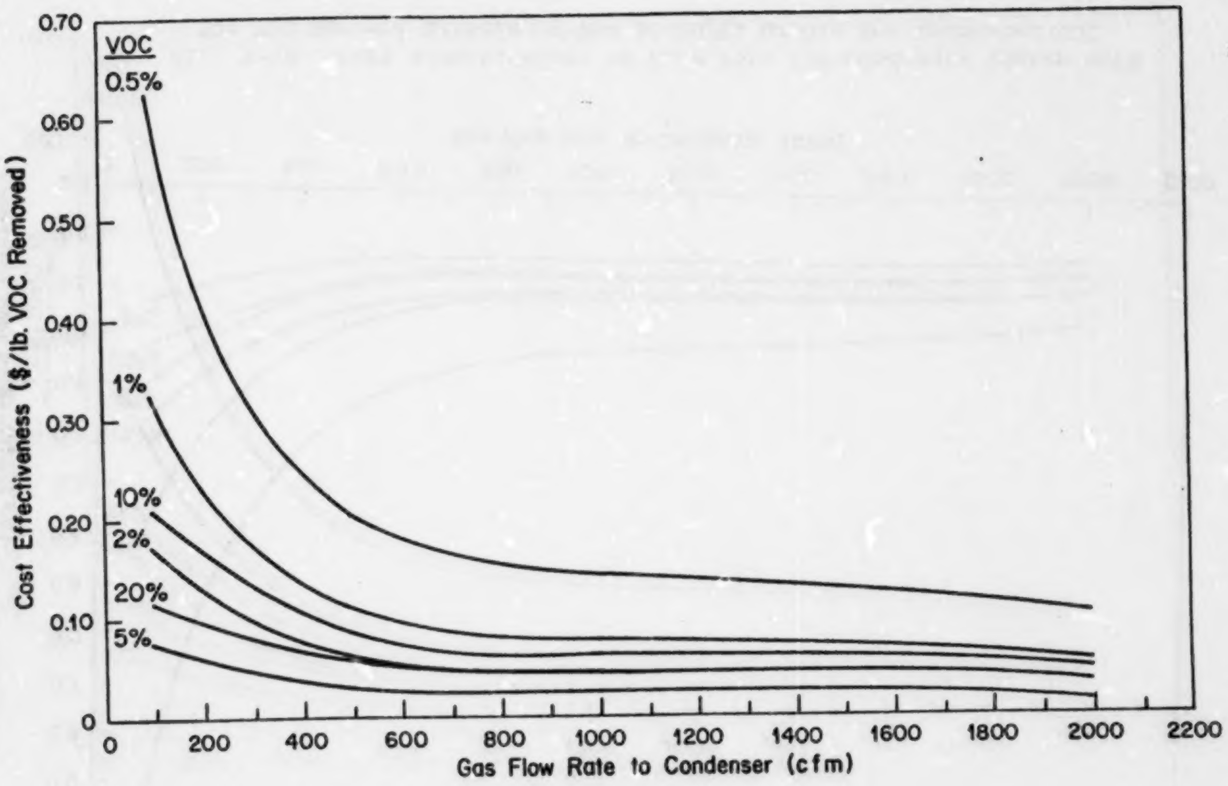

Fig. V-14. Cost Effectiveness vs Flow Rate for Condenser System with 95% VOC Removal Efficiency and No VOC Recovery Credit

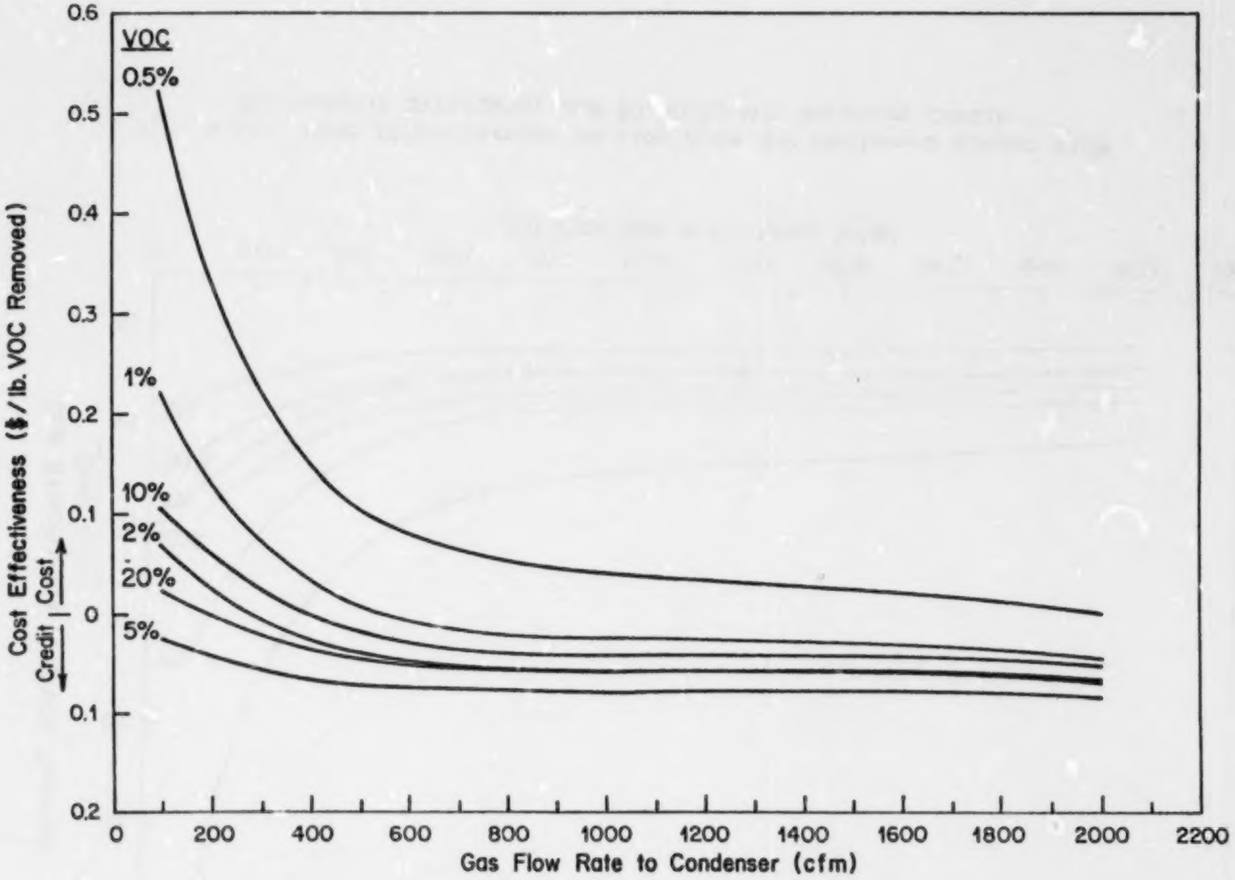

Fig. V-15. Cost Effectiveness vs Flow Rate for Condenser System with 95% Removal Efficiency and $0.10/lb VOC Recovery Credit

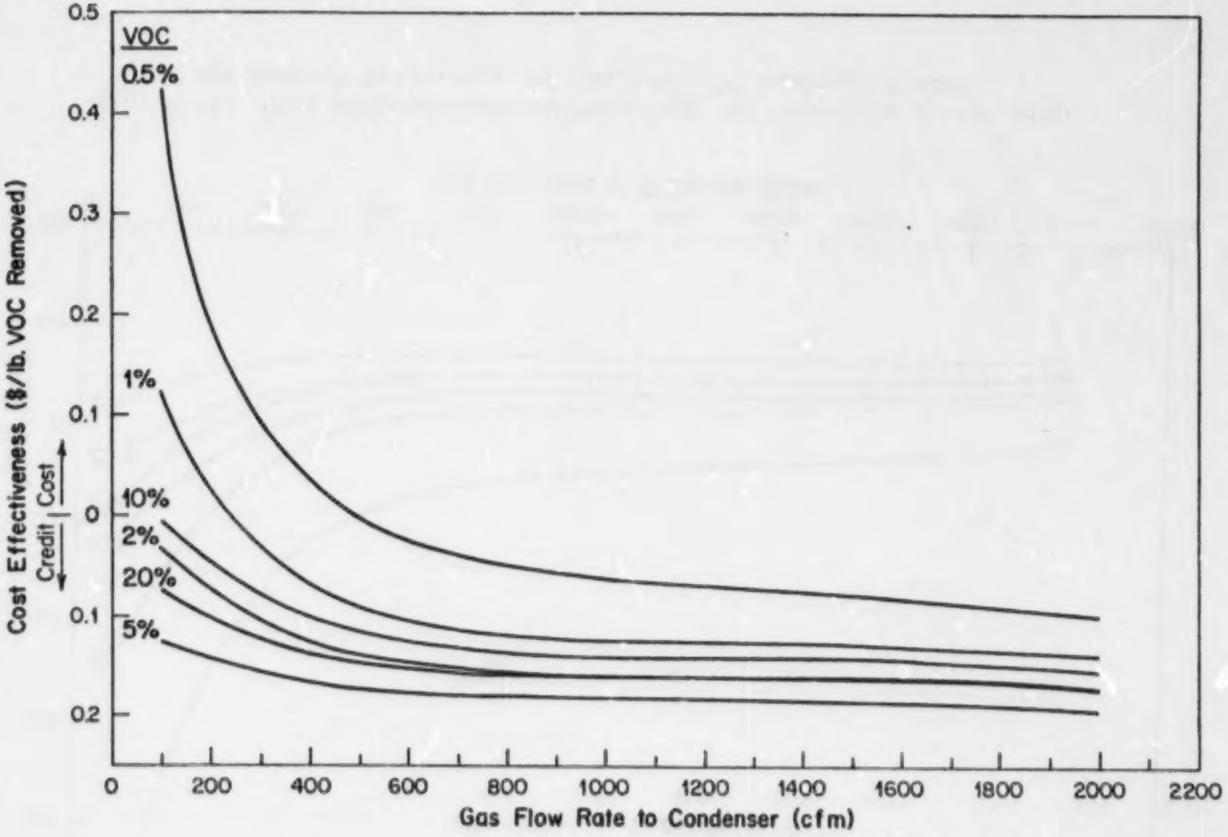

Fig. V-16. Cost Effectiveness vs Flow Rate for Condenser System with 95% Removal Efficiency and $0.20/lb VOC Recovery Credit

Table V-7. Energy-Effectiveness Summary

VOC Removal Efficiency	Energy Effectiveness (Btu/lb of VOC) at VOC Concentrations of 20%	10%	5%	2%	1%	0.5%
50%	67.0	72.9	86.9	123.3	176.9	311.0
80%	95.9	108.9	133.4	206.0	324.9	529.3
95%	194.7	229.4	294.5	483.5	773.0	1359.7

VI. SUMMARY AND CONCLUSIONS

Condensation as an emission control method is currently most widely used as a preliminary or auxiliary step for other control devices. When condensation only is used for control of VOC emissions at atmospheric pressures, it is done in conjunction with a refrigeration unit to supply coolant at temperatures that will allow acceptable VOC recovery efficiencies.

The suitability of condensation as a VOC emission control method compared to other alternatives (primarily carbon adsorption and thermal oxidation) depends on the concentration of the VOC in the treated stream, the flow rate of the treated stream, and the value of the recovered VOC components.

Estimates of capital costs, operating costs, and cost effectiveness were developed for a number of combinations of conditions or variables to illustrate the effects that changes in these variables would have on the costs. Some of the conclusions derived from the cost evaluation are as follows:

1. At low VOC concentrations the cost effectiveness of condensation is very sensitive to the gas flow rate.
2. In general condensation systems are economical as an emission control provided that the gas stream contains high concentrations of VOC that have a value of at least $0.10/lb.
3. The cost effectiveness of condensation at low flow rates and low VOC concentrations is usually uneconomical regardless of the recovery efficiencies achieved.

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2. J. H. Danielson, Air Pollution Engineering Manual, 2d ed., Air Pollution Control District, County of Los Angeles.

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5. Control of Hydrocarbons from Tank Truck Gasoline Loading Terminals, Guideline Series, EPA-450/2-77-026 (OAQPS No. 1.2-082) (October 1977).

6. Marine Hydrocarbon Vapor Recovery Units for Loading Gasoline Into: Tankers, Barges, and Fixed Roof Storage Tanks, Edwards Engineering Corp., Pompton Plains, NJ.

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*When a reference number is used at the end of a paragraph or on a heading, it usually refers to the entire paragraph or material under the heading. When, however, an additional reference is required for only a certain portion of the paragraph or captioned material, the earlier reference number may not apply to that particular portion.

APPENDIX A

BREAKDOWN OF CAPITAL COSTS FOR CONDENSER SECTION AND REFRIGERATION UNIT

BREAKDOWN OF CAPITAL COSTS FOR CONDENSER SECTION AND REFRIGERATION UNIT

The installed capital costs for the condenser section, which includes a shell-and-tube condenser, a storage tank, a pump and the necessary piping and instruments, are plotted in Fig. A-1 as a function of the condenser area, with the tank, pump, pipes, and instruments sized accordingly. A 30% allowance for contingencies is included in these costs. The installed capital costs for the refrigeration unit, which includes the compressor, the condenser expension valve, the evaporator, controls, foundations, and all auxiliary components except extensive runs of piping for the product or coolant lines, are plotted in Fig. A-2 as a function of the amount of refrigeration required (tons) at coolant temperatures ranging from +40°F to -60°F.

The costs plotted in Fig. A-1 are for carbon steel, type 304 stainless steel, and Monel, but the equipment cost estimates given in Sect. V are based on the use of carbon steel construction throughout.

Other criteria used in the selection of equipment parameters and cost estimates are as follows:

1. Condensers: carbon steel; 150 psig; fixed-tube sheet; 1-in.-diam tubes 8 ft long; piping, same material as tubes and shell; include foundation or share of structure
2. Storage tank: 50 psi; vertical type, ASME; concrete foundation; platform, dike, and transfer piping at tank
3. Pump: ductile iron, single-stage centrifugal pump, includes 200 ft of conduit run, standard valving, and 100 ft of carbon steel; suction plus discharge piping
4. Instruments: temperature indicator, temperature transmitter, control valve, and level transmitter with hi-lo start-stop operation of pump

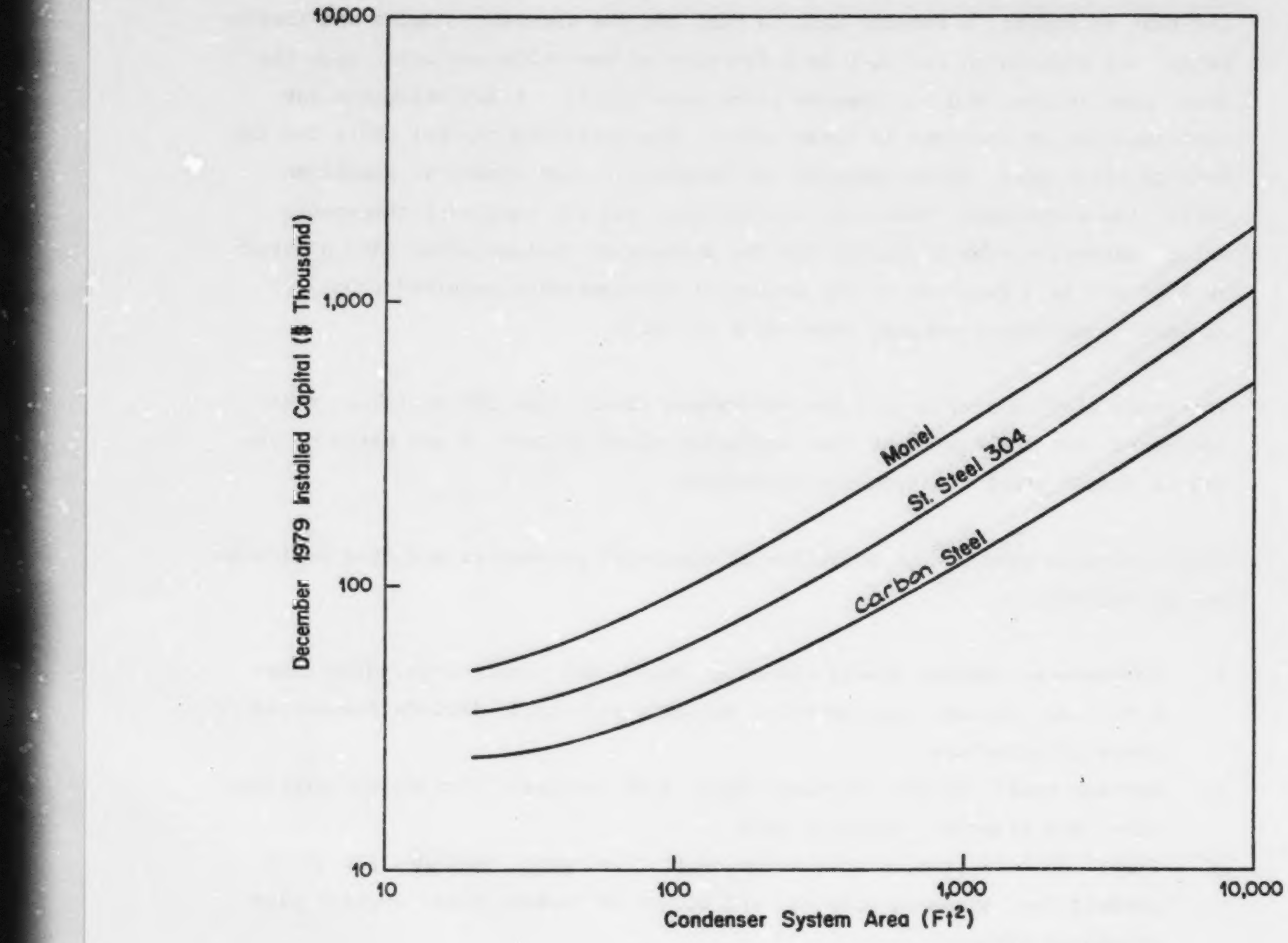

Fig. A-1. Installed Capital Cost vs Condenser Area for Various Materials of Construction for a Complete Condenser Section

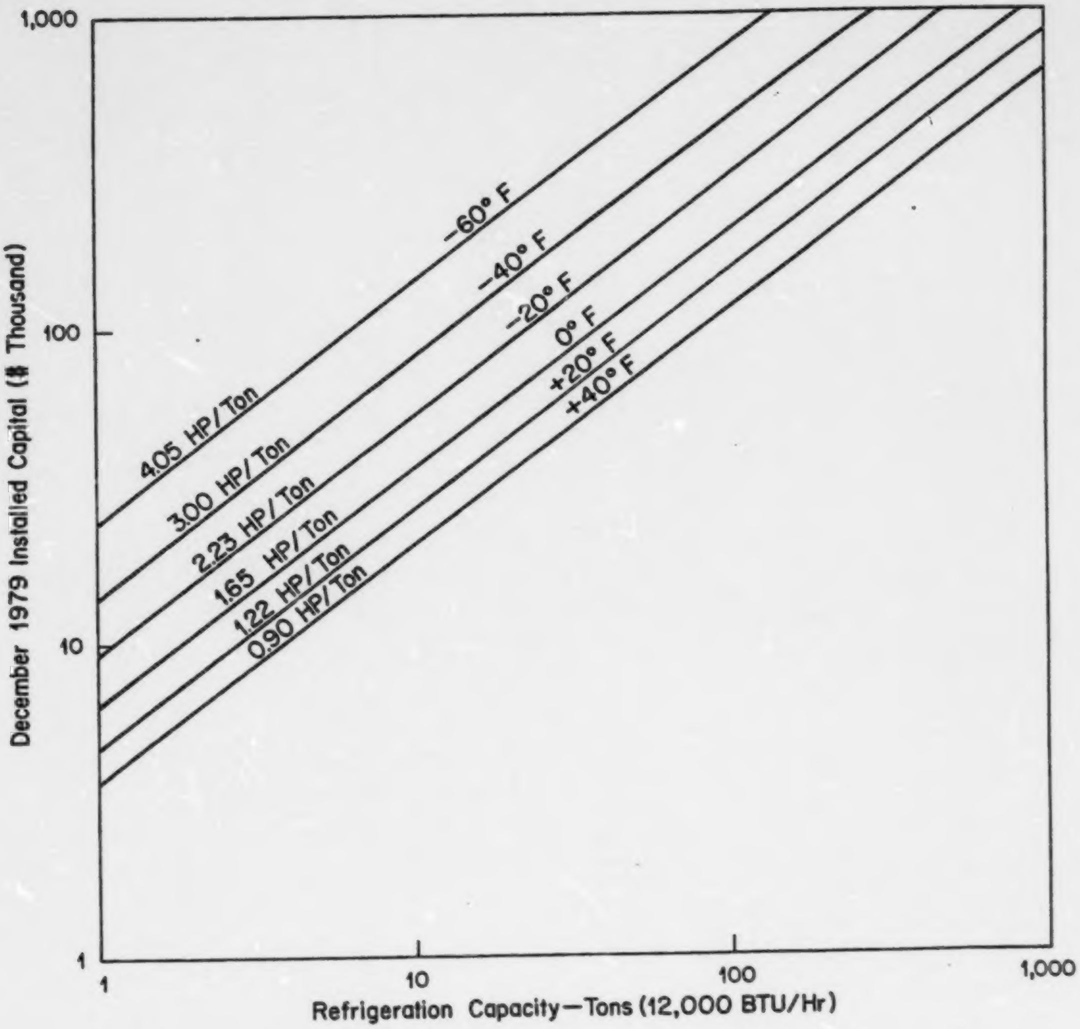

Fig. A-2. Installed Capital Costs vs Refrigeration Capacity at Various Coolant Temperatures for a Complete Refrigeration Section

APPENDIX B

SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

The following sample calculations are based on a vent gas stream flowing at a rate of 1000 cfm and having a VOC content of 1.0%. The recovery rate required is 95%. The cost effectiveness is determined for a recovered-product value of $0.10/lb.

Capital cost

$141,000 (from Fig. V-3)

Fixed cost

Capital cost X 0.29^a = $141,000 X 0.29 = $40,900

Labor cost

$(876 \text{ hr X } 15\ \$/\text{hr})^a = \$13{,}100$

Power cost

In order to estimate the power cost for refrigeration the total heat transfer (Q) required must be determined. The total heat transfer required is a summation of the specific heat of air, the specific heat of the VOC, and the latent heat of vaporization of the VOC at the temperatures required for 95% recovery efficiency.

Material Balance:

Gas flow = 1000 cfm ÷ 379 ft^3/lb-mole X 60 min/hr = 158.311 lb-moles/hr
VOC = 158.311 lb-moles/hr X 1.0% = 1.583 lb-moles X 60 AMW^b = 95 lb/hr
Air = 158.311 lb-moles/hr X 99% = 156.73 lb-moles X 29 AMW^b = 4,550 lb/hr

Energy Balance:

Total heat transferred (Q) = air specific heat + VOC specific heat + VOC latent heat
Air = 4,550 lb/hr X 0.24 $Btu/(lb)(°F)^c$ X $(80°F - 1.8°F)^d$ = 85,400 Btu/hr
VOC = 95 lb/hr X 0.50 $Btu/(lb)(°F)^c$ X $(80°F - 1.8°F)^d$ = 3,710 Btu/hr
VOC = 95 lb/hr X 200 Btu/lb^c X 95% recovered = 18,040 Btu/hr
Q = 85,400 Btu/hr + 3,710 Btu/hr + 18,040 Btu/hr = 107,150 Btu/hr

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[a] See Table V-2.

[b] Average molecular weight.

[c] Based on assumptions given in Sect. III-B.

[d] See Table III-1.

$$\text{Refrigeration} = \frac{Q}{12{,}000\ \text{(Btu/hr)/ton}} = \frac{107{,}150\ \text{Btu/hr}}{12{,}000\ \text{(Btu/hr)/ton}} = 8.9\ \text{tons/hr}$$

$$\text{Power} = \frac{8.9\ \text{tons/hr X 2.23 hp/ton[e]}}{0.85\ \text{compressor efficiency X 0.85 motor efficiency}} = 27.4\ \text{hp/hr}$$

= 27.4 hp/hr X 0.746 kWh/hp X 8760 hr/yr = 179,058 kWh/yr

= 179,058 kWh/yr X $0.03/kWh[a] = $5,400/yr

Credit

lb of VOC recovered X $0.10/lb

Flow = 1000 cfm = 158.311 lb-moles/hr

= 158.311 lb-moles/hr X 1.0% = 1.583 lb-moles of VOC X 60 AMW[b] = 95 lb/hr

= 95 lb/hr X 95% X 365 days/yr X 24 hr/day = 790,590 lb/yr

= 790,590 lb/yr X $0.10/lb = $79,100

Net annual cost

$40,900 + $13,100 + $5,400 - $79,100 = $19,700 (credit)

Cost effectiveness

$19,700 ÷ 790,590 lb = $0.025/lb (credit)

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[e] See Fig. A-2.

REPORT 3

CONTROL DEVICE EVALUATION
GAS ABSORPTION

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October 1980

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I. INTRODUCTION

Gas absorption is an operation in which one or more soluble components of a gas mixture are separated from the mixture by selective dissolution in a liquid, termed the solvent. The reverse operation, termed stripping or desorption, is frequently used for recovery of the absorbed components from the solvent. Gas absorption is widely used within the chemical industry for the separation and purification of gaseous process streams and is treated extensively in basic chemical engineering textbooks.[1—4]

Gas absorption as an emission control method is currently most widely used for the removal of water-soluble inorganic contaminants (e.g., sulfur dioxide, hydrogen sulfide, hydrogen chloride, and ammonia) from air streams, with water being the most common solvent or scrubbing fluid used. Water may also be used for the absorption of organic compounds that have relatively high water solubilities (e.g., most alcohols, organic acids, aldehydes, ketones, amines, and glycols). For organic compounds that have low water solubilities, other solvents (usually organic liquids with low vapor pressures) are used. The suitability of gas absorption as a VOC emission control method is generally dependent on the following factors: (1) availability of a suitable solvent (solvent properties are discussed in Sect. II-C), (2) VOC removal efficiency required, (3) recovery value or terminal disposal cost of the contained VOC, (4) capacity required for handling vapors, and (5) VOC concentration in the inlet vapor (absorption is usually considered when the VOC concentration is above 200—300 ppmv). Once it is determined that absorption is technically feasible, it can be compared (for efficiency and cost effectiveness) with other VOC controls (primarily carbon adsorption and thermal oxidation).

---

[1] T. K. Sherwood and R. L. Pigford, Absorption and Extraction, McGraw-Hill, New York, 1952.

[2] R. E. Treybal, Mass Transfer Operations, 2d ed., McGraw-Hill, New York, 1968.

[3] R. H. Perry and C. H. Chilton, Chemical Engineers Handbook, 5th ed., McGraw-Hill, New York, 1973.

[4] W. L. McCabe and J. C. Smith, Unit Operations of Chemical Engineering, 2nd ed., McGraw-Hill, New York, 1967.

II. SYSTEM DESCRIPTION

A. ABSORPTION EQUIPMENT

1. General

Gas absorption equipment is designed to provide thorough contact between the gas and the liquid solvent in order to permit interphase diffusion of the material. The rate of mass transfer between the two phases is largely dependent on the surface area exposed. Other factors governing the absorption rate, such as the solubility of the gas in the particular solvent and the degree of chemical reaction, are characteristic of the constituents involved and are more or less independent of the equipment used. The types of equipment that are commonly used for gas-liquid contact operations include packed towers, plate or tray towers, spray chambers, venturi absorbers, and vessels with sparging equipment. The use of venturi absorbers, spray chambers, and sparging is generally limited to the control of particulate matter and highly soluble gases requiring very few transfer units. They are infrequently used for the control of VOC emissions in dilute concentration. The following discussion is therefore limited to packed and tray towers.

2. Packed Towers

A schematic diagram of a typical packed tower is shown in Fig. II-1.[1] The packing is designed to expose a large surface area. When the packing surface is wetted by the solvent, it presents a large area of liquid film for contact by the solute gas.

Usually the flow through a packed column is countercurrent, with the liquid introduced at the top to trickle down through the packing while gas is introduced at the bottom to pass upward through the packing. This results in the highest possible efficiency, since, as the solute concentration in the gas stream decreases as it rises through the tower, fresher solvent is constantly available for contact. Consequently maximum average driving force is obtained for the diffusion process throughout the entire column.

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[1] J. A. Danielson, Air Pollution Engineering Manual, 2d ed., Air Pollution Control District, County of Los Angeles.

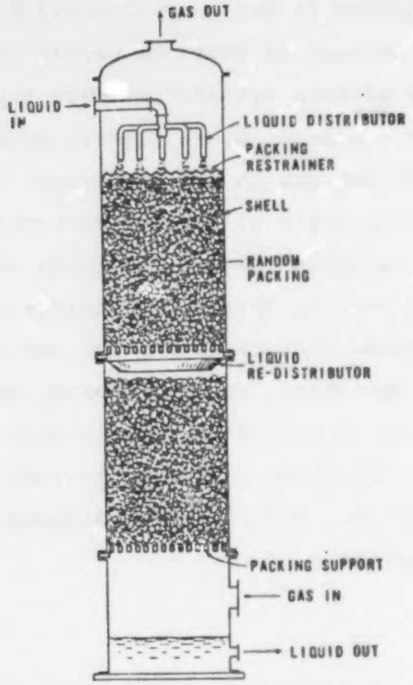
GAS OUT
LIQUID IN
LIQUID DISTRIBUTOR
PACKING RESTRAINER
SHELL
RANDOM PACKING
LIQUID RE-DISTRIBUTOR
PACKING SUPPORT
GAS IN
LIQUID OUT

Fig. II-1. Schematic Diagram of a Packed Tower (from ref 1).

The packing used should be able to provide a large surface area, should be shaped to give a large void space when packed, should be strong enough to be handled and installed without excessive breakage, and should be chemically inert and inexpensive. Although materials such as rock, gravel, and coke are occasionally used, most packing consists of various manufactured shapes. The most common type is Raschig rings, which consist of hollow cylinders having an external diameter equal to their length. Other shapes include Berl® saddles, Intalox® saddles, Pall® rings, Hypak,® and spiral-type rings. Although slotted rings such as Pall rings or Hypak are generally higher in unit cost than Rashchig rings, their superior performance may permit the use of smaller columns with correspondingly lower capital costs. Figure II-2[1] shows several of these common shapes.

3. Plate or Tray Tower

In contrast to packed towers, where gas and solvent are in continuous contact throughout the packed bed, plate towers employ stepwise contact by means of a number of trays or plates that are arranged so that the gas is dispersed through a layer of liquid on each plate. Each plate is more or less a separate stage, and the number of plates required is dependent on the difficulty of the mass-transfer operation and the degree of separation required.

The bubble-cap plate or tray has been the most common type used in the past, and most general references deal primarily with it in discussions of plate towers. Other types of plates, including perforated trays and valve trays, are currently being widely used in new installations because they are less expensive and their performance is about equal to bubble-cap tray performance.

A schematic section of a bubble-cap tray tower is shown in Fig. II-3.[1] Each plate is equipped with openings (vapor risers) surmounted by bubble caps. The gas rises through the tower and passes through the openings in the plate and through slots in the periphery of the bubble caps which are submerged in liquid. The liquid enters at the top of the tower and then flows across each plate and downward from plate to plate through down spouts. The depth of liquid on the plate and the liquid flow patterns across the plate are controlled by various weir arrangements.

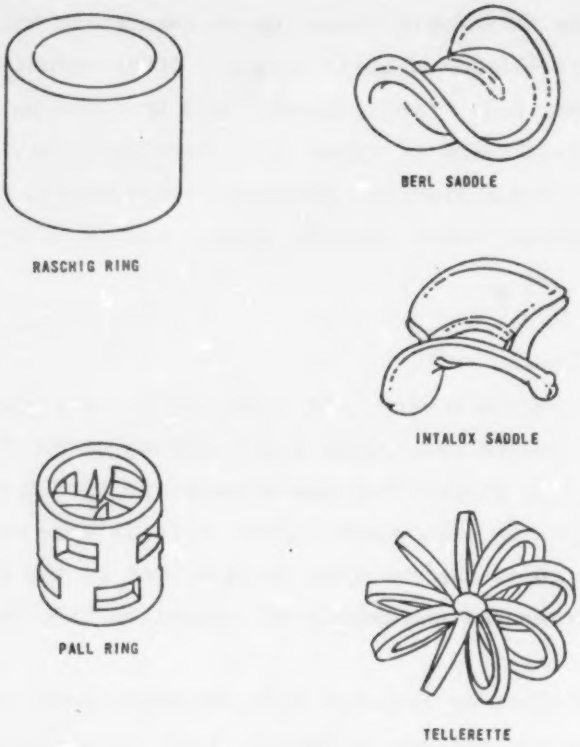
RASCHIG RING
BERL SADDLE
INTALOX SADDLE
PALL RING
TELLERETTE

Fig. II-2. Common Tower Packing Materials (from ref 1).

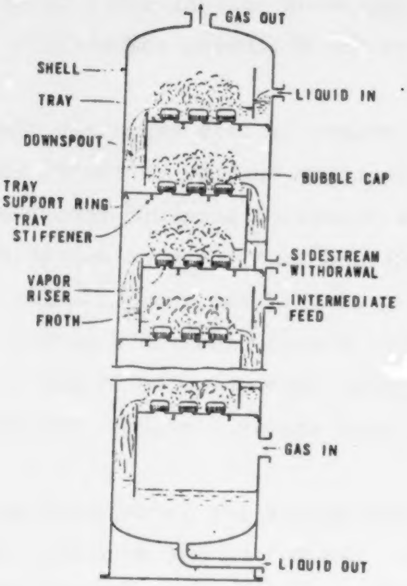
GAS OUT
SHELL
TRAY
LIQUID IN
DOWNSPOUT
BUBBLE CAP
TRAY SUPPORT RING
TRAY STIFFENER
SIDESTREAM WITHDRAWAL
VAPOR RISER
INTERMEDIATE FEED
FROTH
GAS IN
LIQUID OUT

Fig. II-3. Schematic Diagram of a Bubble-Cap Tray Tower (from ref 1).

4. Comparision of Packed and Plate Tower

While devices such as sparged vessels, spray chambers, and venturi absorbers have limited application for gas absorption, the choice of equipment is usually between a packed tower and a plate tower. Both devices have advantages and disadvantages for a given operation, depending on many factors, such as gas and liquid flow rates and degree of corrosiveness of the streams. Final selection will usually be based on the following comparative information:

1. Packed towers are generally less expensive than plate towers when the materials of construction must be corrosion resistant.
2. Packed towers have a smaller pressure drop than plate towers designed for the same throughput and thus are more suitable for vacuum operation.
3. Packed towers are preferred for foamy liquids.
4. The liquid holdup is usually less in a packed tower.
5. Plate towers are preferable when the liquid contains suspended solids since they can be more easily cleaned. Packed towers tend to plug more readily.
6. Plate towers are preferable for large diameters, to minimize channeling and reduce weight. Channeling may be corrected in tall, large-diameter packed towers by the installation of redistribution trays at given intervals.
7. Plate towers are more suitable when the operation involves appreciable temperature variation since expansion and contraction due to temperature change may crush the packing.
8. Plate towers are superior when the heat of solution must be removed at an intermediate location in the tower. The liquid downflow can be collected, cooled externally, and returned more simply in a plate column.
9. Mass-transfer capabilities of packed towers can be predicted with less accuracy than plate towers, often requiring larger safety factors with correspondingly higher capital costs.
10. With other conditions being equal, economic considerations generally favor packed towers of diameters of up to 2 ft and plate towers with diameters of greater than 4 ft.

B. SOLVENT REQUIREMENTS

1. Treybal[2] lists some important aspects that should be considered in selecting absorption solvents:

    1. The gas solubility should be relatively high so as to enhance the rate of absorption and decrease the quantity of solvent required. Solvents chemically similar to the solute generally provide good solubility.
    2. The solvent should have relativly low volatility so as to reduce solvent loss. (This is particularly important in emission control applications as solvent losses may result in additional VOC emissions.)
    3. If possible, the solvents should be noncorrosive so as to reduce construction costs of the equipment.
    4. The solvents should be inexpensive and readily available.
    5. The solvent should have relatively low viscosity for suitable mass-transfer rates and flooding characteristics.
    6. Ideally, the solvent should be nontoxic, nonflammable, and chemically stable and have a low freezing point.

When applicable, water offers certain distinct advantages over other solvents. Because the actual cost of the solvent is very low, water can frequently be used on a once-through basis, with the effluent water being discharged to wastewater treatment either directly from the absorber or after a subsequent stripping operation. The discharge of absorber effluent water without stripping is usually practiced only when the absorbed VOC components are present in very low concentrations and/or have little or no recovery value. It is not considered to be an acceptable practice if significant secondary emissions or degradation in the quality of discharged water results.

When water is stripped before being discharged to wastewater treatment, once-through use may result in less stringent stripping requirements than those involved with solvent recycle. (When the solvent is recycled, incomplete stripping reduces subsequent absorption efficiency.) Once-through use of water also usually reduces cooling requirements and the corresponding heat-exchanger capital costs.

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[2] R. E. Treybal, Mass Transfer Operations, McGraw-Hill, New York, 1955.

An additional advantage in using water as a solvent compared to the use of organic solvents is that solvent losses do not result in additional VOC emissions or organic concentration in wastewater. Although organic solvents are selected to minimize these losses (i.e., low vapor pressure), some losses will result.

C. SYSTEM FLOWSHEETS

Absorption system requirements for VOC control applications and the corresponding equipment configurations may vary significantly, depending on specific applications and control requirements. The flow sheets discussed below illustrate several examples.

Figure II-4 illustrates the simplest configuration, in which the solvent (usually water) is used on a once-through basis and is then either discharged to a waste-water treatment system or introduced as a process water stream. The possibility of using organic solvents on a single-pass basis may exist in those few situations where fresh solvent is available in large quantity as a process raw material or fuel. For instance, a small vent stream might be scrubbed with oil on a single-pass basis before being burned as fuel. With this system the only major equipment items required in addition to the absorption tower are, possibly, a blower to provide for tower pressure drop and a pump to discharge the effluent solvent.

In the system shown in Fig. II-5 the solvent (usually water) is used on a single-pass basis but is stripped before being discharged. Additional major equipment items, compared to those shown in Fig. II-4, include a stripping tower, an additional pump, and a number of heat exchangers. Heat exchangers may include a feed-effluent exchanger, a steam-heated feed preheater, and a water-cooled reflux condenser. The effluent liquid from the absorber is usually preheated to near its boiling point before it is introduced into the stripping tower. The feed-effluent heat exchanger reduces steam requirements in the steam preheater and cools the stripped solvent to well below its boiling point before it is discharged. As is shown, the heat required for vaporization in the stripper may be introduced by steam being directly sparged into the base and the condensed steam being discharged with the stripped solvent.

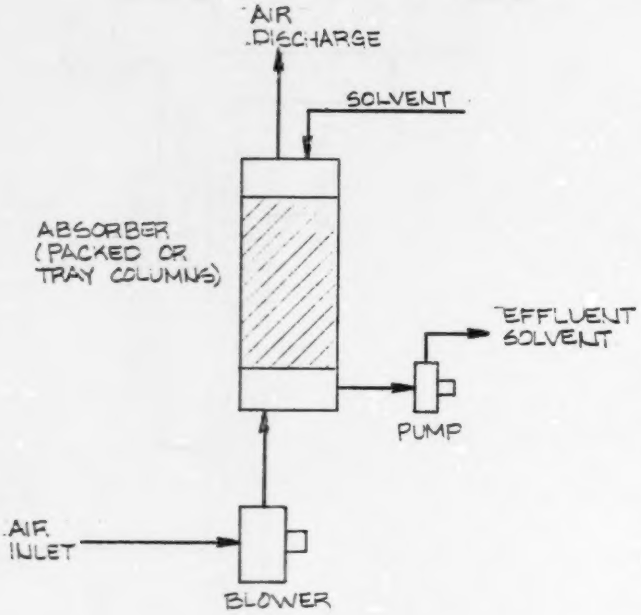
AIR
DISCHARGE
SOLVENT
ABSORBER
(PACKED OR
TRAY COLUMNS)
EFFLUENT
SOLVENT
PUMP
AIR
INLET
BLOWER

Fig. II-4. Simple Absorption System.

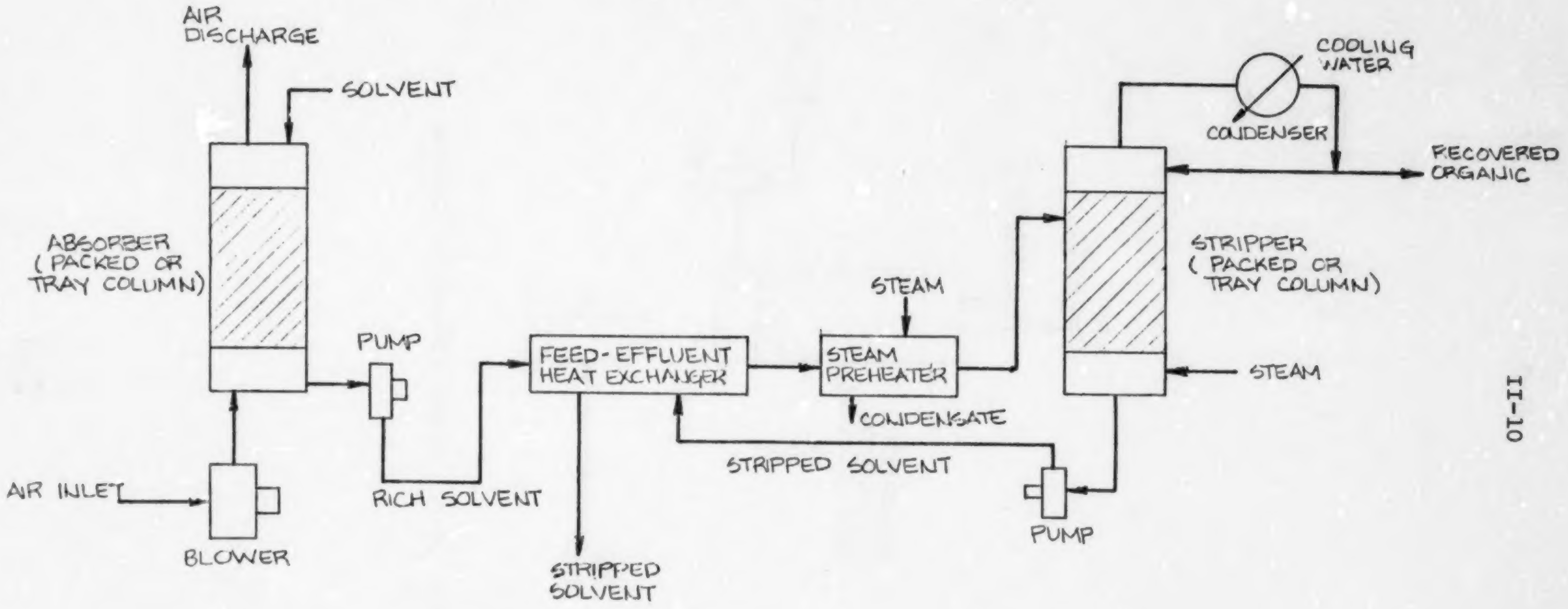
AIR DISCHARGE
SOLVENT
ABSORBER (PACKED OR TRAY COLUMN)
AIR INLET
BLOWER
PUMP
RICH SOLVENT
FEED-EFFLUENT HEAT EXCHANGER
STRIPPED SOLVENT
STEAM
STEAM PREHEATER
CONDENSATE
STRIPPED SOLVENT
COOLING WATER
CONDENSER
RECOVERED ORGANIC
STRIPPER (PACKED OR TRAY COLUMN)
STEAM
PUMP

Fig. II-5. Absorption System with Stripping Tower (Once-Through Solvent Usage).

The last flow sheet (Fig. II-6) depicts a typical absorption-stripping system that uses an organic-liquid solvent and recycles the stripped solvent to the absorber. Additional equipment items required (compared to those in Fig. II-5) include a steam-heated reboiler and a water-cooled solvent cooler. Because solvent usage and losses must be minimized, both absorber and stripper operating requirements are generally more stringent than when water is used, with correspondingly higher capital and operating costs. For example, in order to attain very low VOC concentration in the air discharged from the absorber, the equilibrium concentration of residual VOC in the recycled solvent must be reduced to a very low level. With once-through usage of water as the solvent the initial equilibrium VOC concentration of the solvent is nil, and the stripping efficiency has no effect on absorber performance.

Other absorption-stripping system variations (not shown) that may significantly affect capital and operating costs include requirements for low-temperature conditions (requiring refrigeration equipment and additional heat exchangers), vacuum stripping, and operation at elevated pressures. Corrosive conditions, if present, will result in more stringent construction material requirements and in correspondingly higher capital costs.

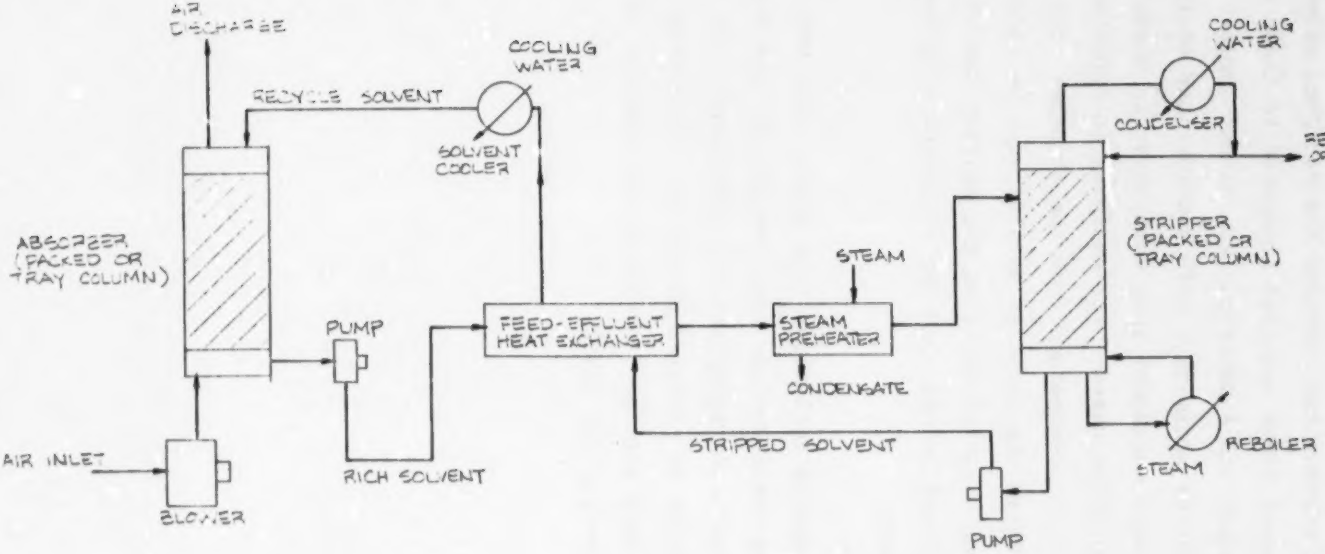
AIR DISCHARGE
RECYCLE SOLVENT
COOLING WATER
SOLVENT COOLER
ABSORBER (PACKED OR TRAY COLUMN)
PUMP
AIR INLET
BLOWER
RICH SOLVENT
FEED-EFFLUENT HEAT EXCHANGER
STEAM
STEAM PREHEATER
CONDENSATE
STRIPPED SOLVENT
PUMP
COOLING WATER
CONDENSER
RECOVERED ORGANIC
STRIPPER (PACKED OR TRAY COLUMN)
REBOILER
STEAM

Fig. II-6. Absorption System with Stripping Tower (Solvent Recycled to Absorber).

III. SYSTEM EFFICIENCIES

A. GENERAL

The VOC removal efficiencies of absorption systems are limited by the driving force available to transfer the VOC from the gas stream to the liquid solvent. The available driving force at each point within a countercurrent absorption tower is determined by the difference between the actual VOC concentrations in the gas stream and solvent at that point and the corresponding equilibrium concentrations. The equilibrium relationships are unique for each VOC-solvent system, and the equilibrium values at various concentrations are generally determined experimentally and displayed as an equilibrium curve. Figure III-1 shows a typical equilibrium curve, in which x, the concentration of VOC in the solvent, expressed as the mole fraction, is plotted versus the corresponding equilibrium concentration (mole fraction) in the gas. As is illustrated by Fig. III-1, the equilibrium curve typically approximates a straight line (constant slope, m) near the origin, where VOC concentrations in the solvent and the gas are low, and increasingly diverges from a straight line at increasing concentrations.

The relationships between attainable VOC removal efficiency, the equilibrium curve slope, and the required liquid-gas mole ratio and/or the corresponding absorption tower height (number of transfer units in a packed column or theoretical trays in a tray column) are shown by Figs. III-2 and III-3 respectively.

Figure III-2, which applies to packed columns, is based on the following equation:[1]

$$N_{OG} = \frac{\ln\left[\left(1 - \frac{mG_M}{L_M}\right)\left(\frac{y_1 - mx_2}{y_2 - mx_2}\right) + \left(\frac{mG_M}{L_M}\right)\right]}{1 - (mG_M/L_M)} \quad . \qquad \text{(III-1)}$$

---

[1] A. P. Colburn, Trans. Am. Inst. Chem. Engrs. 35, 211 (1939) (cited in: "Absorption and Extraction," T. K. Sherwood and R. L. Pigford, p 133, Chemical Engineering Series, McGraw-Hill, New York, 1952).

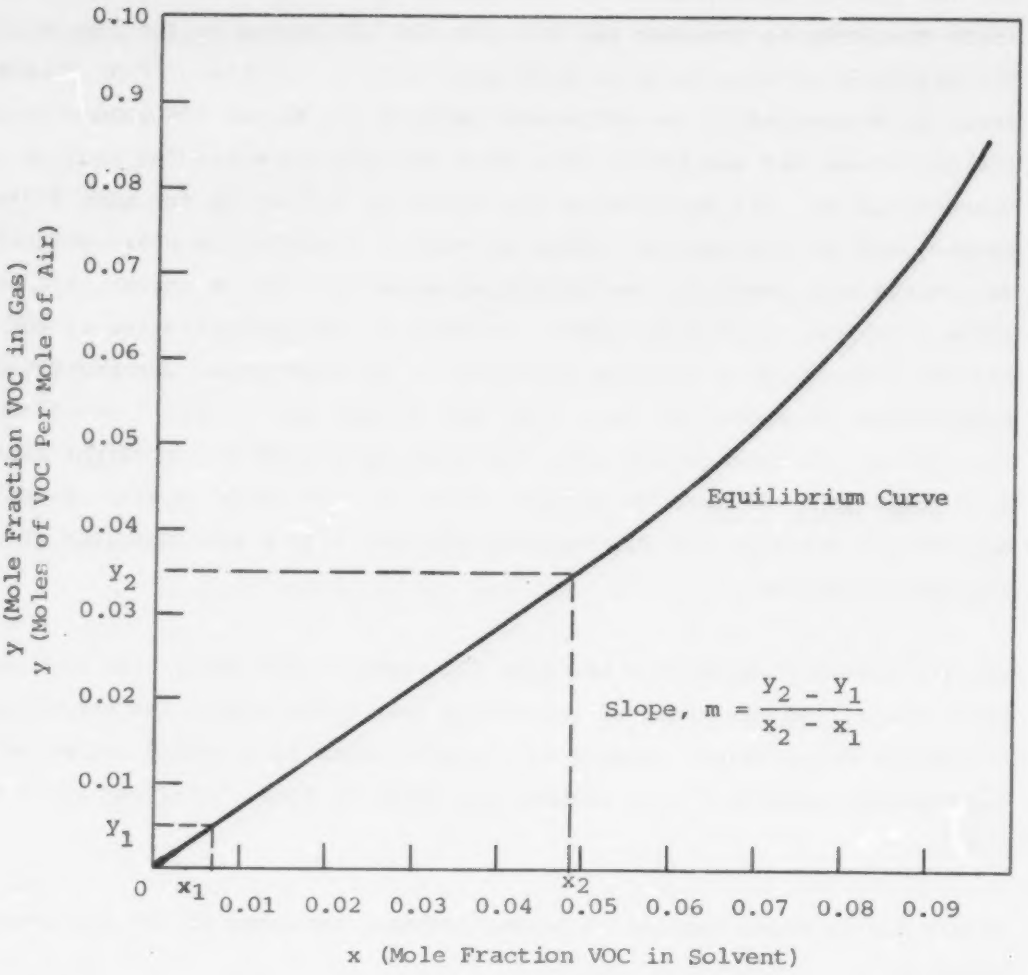

Fig. III-1. Typical Vapor-Liquid Equilibrium Curve for an Absorption System.

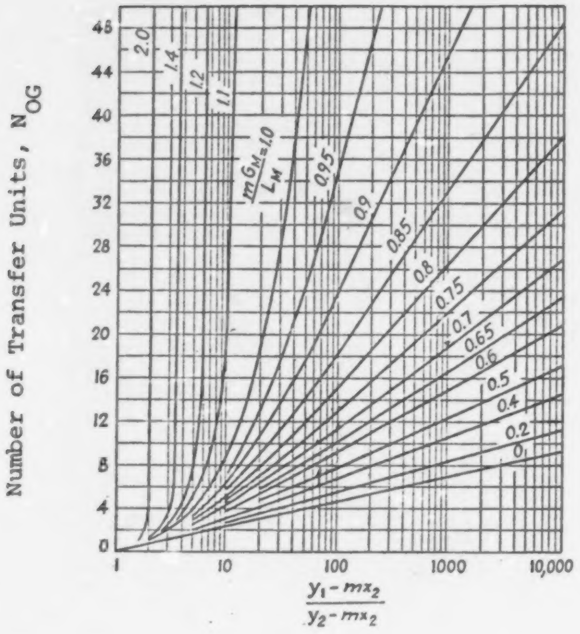

Fig. III-2. Number of Transfer Units in an Absorption Column for Constant mG_M/L_M

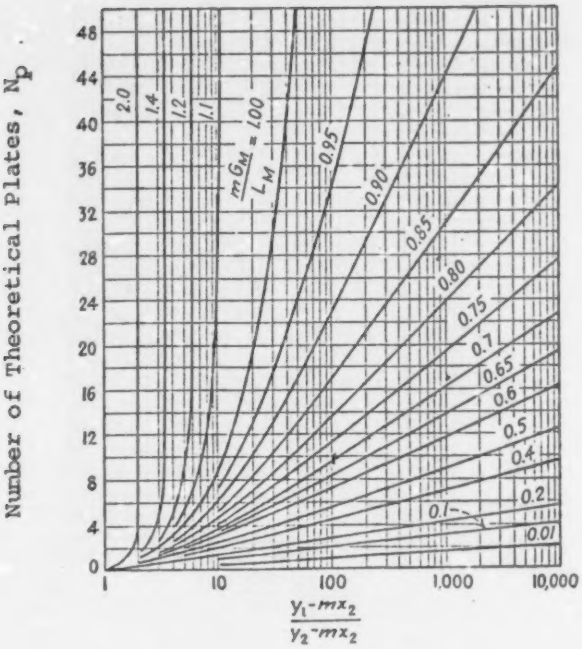

Fig. III-3. Number of Theoretical Plates in an Absorption Column for Constant mG_M/L_M.

249

The terms used in Eq. (III-1) and Fig. III-2 are defined below:

N_{OG} = number of overall gas-phase transfer units,
m = slope of equilibrium curve,
G_M = superficial molar mass velocity of gas, lb-moles/(hr)(ft^2),
L_M = superficial molar mass velocity of liquid, lb-moles/(hr)(ft^2),
y_1 = mole fraction of VOC in inlet gas,
y_2 = mole fraction of VOC in outlet gas,
x_1 = mole fraction of VOC in effluent liquid,
x_2 = mole fraction of VOC in inlet liquid.

The analagous equation for tray columns,[1] which is the basis for Fig. III-3, is as follows:

$$N_P = \frac{\ln\left[\left(1 - \frac{mG_M}{L_M}\right)\left(\frac{y_1 - mx_2}{y_2 - mx_2}\right) + \left(\frac{mG_M}{L_M}\right)\right]}{\ln\,(L_M/mG_M)} \qquad \text{(III-2)}$$

in which N_P is the number of theoretical trays. All other terms in Eq. (III-2) and Fig. III-3 are the same as those used in Eq. (III-1) and Fig. III-2.

The relationships shown in Figs. III-2 and III-3 apply to the condition of constant mG_M/L_M (the equilibrium curve is a straight line). This condition is usually approached closely only with dilute solutions, and more complex and accurate calculations are usually necessary for actual design requirements. However, the relationships shown are useful for order-of-magnitude estimates and for illustrating the relationships between variables.

Equation (III-1) or Fig. III-2 may be used to estimate the number of transfer units required in a packed tower. In order to estimate the total packed height required, the equivalent height of a transfer unit must also be determined. Similarly, in order to estimate the actual number of trays required in a tray tower from the number of theoretical trays predicted by Eq. (III-2) or Fig. III-3, the tray efficiency must be estimated. Sample calculations that illustrate the estimation of transfer-unit height and tray efficiency are given in Appendix B. Examples that illustrate the use of Fig. III-3 to estimate VOC removal efficiency are given in Sects. III-B and III-C.

B. SYSTEM WITH ONCE-THROUGH SOLVENT USAGE

As is discussed in Sect. II, for systems in which the solvent is used on a once-through basis (Figs. II-4 and II-5), which is frequently the case when the solvent is water, the initial VOC concentration of the solvent is usually nil and VOC stripping efficiency has no effect on the VOC removal efficiency of the absorber. Referring to Figs. III-2 and III-3, with once-through solvent usage x_2 becomes 0 and the ordinate $(y_1 - mx_2)/(y_2 - mx_2)$ becomes simply y_1/y_2. The VOC removal efficiency in percent is then expressed as $(1 - y_2/y_1) \times 100$. As an example, if a plate absorption column containing 16 theoretical plates is operated with a gas/liquid mole ratio (G_M/L_M) of 0.35 and if the equilibrium curve slope, m, for the VOC solvent system is approximately 2.0 over the operating range, the value of mG_M/L_M becomes 0.7 (i.e., 2.0 X 0.35). Then, referring to Fig. III-2, the corresponding value of $(y_1 - mx_2)/(y_2 - mx_2)$ is read as approximately 1000 and the corresponding VOC removal efficiency is estimated as (1 - 1/1000) X 100, or 99.9%.

C. SYSTEMS WITH SOLVENT RECYCLE

Systems that utilize organic liquids as solvents usually include the stripping and recycle of the solvent to the absorber (Fig. II-6). In this case the VOC removal efficiency of the absorber is dependent on the solvent stripping efficiency.

Based on the same criteria used in the example in Sect. III-B (i.e., $m = 2.0$, $G_M/L_M = 0.35$, and 16 theoretical plates), on a concentration of 1.0 mole % VOC in the inlet gas, and on a solvent stripping efficiency of 98.0%, the value of $(y_1 - mx_2)/(y_2 - mx_2)$ is again determined as 1000 from Fig. III-2; however, in this case the VOC removal efficiency is less because the mole fraction of VOC in the inlet solvent, x_2, is greater than 0. The value of x_2 must be determined to solve for y_2 in the expression

$$\frac{y_1 - mx_2}{y_2 - mx_2} = 1000. \qquad \text{(III-3)}$$

The value of x_2 may be determined from a VOC material balance across the absorber expressed as

$$(y_1 - y_2)\, G_M = (x_1 - x_2)\, L_M \quad . \tag{III-4}$$

Although y_2 also appears in Eq. (III-4), with a relatively high VOC removal efficiency the effect of neglecting the VOC in the exhaust air is negligible (as shown later in the example) and Eq. (III-4) may be approximated as

$$\frac{x_1 - x_2}{y_1} = \frac{G_M}{LM} \quad . \tag{III-5}$$

Substituting the numerical values in Eq. (III-5):

$$\frac{x_1 - 0.02\, x_1}{0.01} = 0.35, \tag{III-6}$$

Solving for x_1 and x_2:

$x_1 = 0.00357$, and $x_2 = 0.02\, x_1 = 0.0000714$.

Substituting numerical values in Eq. (III-3):

$$\frac{0.01 - (2)(0.0000714)}{y_2 - (2)(0.0000714)} = 1000,$$

Solving for y_2:

$y_2 = 0.000153$.

The corresponding VOC removal efficiency is determined as

$$E = \frac{y_1 - y_2}{y_1} \times 100 = \frac{0.01 - 0.000153}{0.01} \times 100 = 98.5\%.$$

To verify that neglecting the value of y_2 in the material-balance equation [(III-4)] has only a slight effect on the calculated values of x_1 and x_2, the calculated value of y_2 is substituted in Eq. (III-4):

$$\frac{G_M}{L_M}(y_1 - y_2) = x_1 - x_2 \quad ,$$

$$0.35\,(0.01 - 0.000153) = x_1 - 0.02\, x_1 \quad ,$$

then $x_1 = 0.00352$, and $x_2 = 0.0000703$.

This example illustrates the effect of the stripping efficiency on the VOC removal efficiency.

IV. DESIGN CONSIDERATIONS

A. GENERAL

The actual design of an optimum absorption or absorption-stripping system for a given emission control application is relatively complex. An optimum design requires the selection of a combination of equipment and operating conditions that will satisfy emission control requirements at minimum overall cost. Often a change that reduces the cost of one element must be balanced against the effect it has on other costs. Although detailed design procedures are beyond the scope of this report, some of the most significant design considerations and the relationships between them are discussed briefly in this section.[1] For simplicity, these factors are discussed specifically as they apply to absorption-stripping systems using plate or tray towers and designed to control VOC emissions at relatively low concentrations in air, with water used as the solvent on a once-through basis (flowsheet, Fig. II-5).

B. CAPITAL COSTS PARAMETERS

1. Absorber

The diameter of the absorber is primarily a function of the total gas flow rate, and the height is determined primarily by the number of trays required. The number of trays is, in turn, determined by the solvent/gas mole ratio used, the slope of the equilibrium curve for each specific VOC-solvent system, and the VOC removal efficiency required. Thus the combination of the tower height and the solvent rate selected must be balanced for optimum operation. The relationships between the number of trays, the solvent-gas ratio, the operating curve slope, and the VOC removal efficiency are shown by Fig. III-2.

2. Stripping Tower

As with the absorber, the height of the stripper is determined primarily by the number of trays required. The number of trays is, in turn, determined by the relative volatilities of the solvent and the contained VOC (equilibrium curve slope), the reflux ratio used, and the degree of separation (or stripping efficiency) required. A relationship of variables for the stripper similar to that described for the absorber exists (see Fig. III-2); however, because more concentrated gas mixtures occur, the deviation of the actual equilibrium curve from a straight line generally becomes much greater and the assumption of constant mG_M/L_M introduces greater error. As with the absorber, the combination of stripping tower height and reflux ratio must be balanced for optimum cost.

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[1] For a detailed study of wet scrubber systems see: S. Calvert *et al.*, Wet Scrubber System Study. Vol. 1. Scrubber Handbook, PB—213 016, NTIS (July 1972).

The required tower diameter is primarily a function of the vapor flow rate. The vapor flow rate is, in turn, determined by the reflux ratio used and by the solvent flow rate from the absorber. Therefore the required diameter becomes dependent on the height selected, and, as the liquid rate is dependent on the absorber design parameters, the absorber and stripper parameters become interdependent and must be balanced for optimum cost.

3. Blower

Blower capital costs are primarily dependent on horsepower requirements. The required horsepower is determined by the air flow rate and by the pressure increase (ΔP) that must be developed to overcome the pressure drop through the absorber and inlet duct. The absorber pressure drop is roughly proportional to the number of trays in the absorber tower, and therefore the effect of changes on blower capital costs and energy requirements must be considered in selecting the optimum number of trays in the absorber. (The pressure drop is usually significantly less in packed towers than in tray towers and may be a significant factor in the type of tower selected).

4. Heat Exchangers

a. General——The capital cost of heat exchangers is primarily a function of the heat-transfer surface area required. For a specific application in which the heat-transfer coefficients and the required temperatures remain relatively constant, the required areas will be approximately proportional to the required heat-transfer rates and to the corresponding flow rates of fluids that are heated, cooled, vaporized, or condensed.

b. Feed-Effluent Heat Exchanger——The required areas and the corresponding capital costs are primarily dependent on the solvent flow rates.

c. Steam Preheater——The capital cost primarily depends on the solvent flow rate.

d. Stripper Condenser——The capital cost primarily depends on the vapor rate in the stripper, which in turn is determined by the solvent flow rate and the reflux ratio selected.

5. Other Capital Requirements

Most of the other capital items to be considered, including piping and instrumentation, are either relatively minor, remain relatively constant, or are independent of other design considerations.

C. OPERATING COST (CREDIT) PARAMETERS

1. General

Certain operating cost components are interdependent with the equipment design parameters and must be considered in arriving at an optimum design for an absorption-stripping system. Following is a brief discussion of primary operating cost components.

2. Solvent Cost

For the flow sheet shown in Fig. II-5 in which the solvent (water) is used on a once-through basis, the cost of using process water must be considered in the design of the absorber tower. The combination of the number of trays, or the height of the absorber tower, and the corresponding liquid rate required must be balanced for optimum cost.

3. Electrical Power

Electrical power is used primarily for operation of blowers and pumps. Blower power requirements are primarily determined by the quantity of gas passing through the absorber and by the absorber-tower pressure drop. Since pressure drop is primarily dependent on the type of tower selected (plate or packed) and on the number of plates or height of packing required, electrical power usage must be considered in arriving at the optimum absorber tower design.

Power requirements for pump operation are generally relatively small compared to requirements for blower operation. The power required for pump operation will be roughly proportional to the liquid rate through the system and will therefore vary with the liquid/gas ratio selected.

4. **Process Steam**

Steam is used for heating the stripper feed (feed preheater) and for vaporization in the stripper tower, by direct injection or by means of a reboiler. Preheater steam requirements are determined primarily by the liquid flow rate to the stripper.

The quantity of steam for vaporization is determined primarily by the liquid flow rate and by the reflux ratio selected in the design of the stripping tower, and thus vaporization steam usage is influenced by both absorber and stripper design.

5. Cooling Water

The primary use of cooling water is in the stripper condenser. The quantity used will depend on the liquid flow rate and on the stripping-tower reflux ratio.

6. Wastewater Treatment

Wastewater treatment costs are usually dependent on both the quantity of wastewater discharged and the VOC concentration (usually measured as BOD or COD). For a once-through absorber-stripper system in which the solvent (water) is discharged to wastewater treatment, treatment costs will be dependent on the liquid flow rate to the absorber and on the VOC removal efficiency obtained by the stripper. Treatment costs will therefore be influenced by the design of both the absorber and the stripper.

7. Product Recovery Credits

Product recovery credits will be determined by the volume of gas treated and the corresponding VOC concentration, by the unit value of the specific organic compounds (either as process materials or as fuel), and by the removal efficiencies of the absorber and stripping towers. As removal efficiencies are influenced by specific design parameters (e.g., tower height, reflux ratio) they must be considered in the design of an optimum system.

V. COST AND ENERGY IMPACTS OF GAS ABSORPTION SYSTEMS

A. CAPITAL COST ESTIMATES

1. General

Estimated capital costs for total system combinations are presented here (Table V-I) and in Appendix A. The estimated costs represent the total investment, including all indirect costs such as engineering and contractors' fees and overheads, required for the purchase and installation of all equipment and material to provide a facility as described. These are battery-limit costs and do not include provisions for bringing utilities, services, or roads to the site; backup facilities; land; required research and development; or process piping interconnections that may be required within the process(es) that generate the waste gas fed to the absorber systems.

The estimated costs are based on a new-plant installation; no retrofit cost considerations are included. Such costs are usually higher than those for a new-site installation for a similar system and include, for example, demolition, crowded construction working conditions, scheduling construction activities with production activities, and longer interconnecting piping. These factors are so site-specific that no attempt has been made to provide costs. For specific cases, rough costs can be obtained by using the new-site data and adding as required for a specific retrofit situation.

Capital cost estimates were developed by the summation of installed capital costs for the major individual components of each system. These installed capital costs are based on IT Enviroscience experience adjusted to a December 1979 basis. In addition to the sum of the itemized capital costs an allowance of 30% is included in overall capital cost estimates to cover the cost of miscellaneous items that were not included in the simplified flowsheets used.

2. Model Systems

The capital cost, annualized cost, and cost-effectiveness curves given in Figs. V-1 through V-23 were developed for two model systems illustrated by the process flow sheets of Figs. II-4 and II-5, in which the solvent is used on a once-through basis, either without (Fig. II-4) or with (Fig. II-5) a stripping step included.

Table V-1. Capital Cost Summary for Absorber and Stripper Systems

Absorber Conditions: VOC removal, 99%; $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, and 5.0 wt %.
Stripper Conditions: Organic removal, 99%; steam ratio = 0.2 mole of steam/mole of air in.

	Capital Cost (10^3 \$) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
Equipment	1.0	10	100	1.0	10	100	1.0	10	100
Absorber System									
Tower and trays (packing)	33.6	133.8	741.1	42.2	165.6	870.9	48.2	188.2	965.8
Blower	29.7	100.2	293.5	34.5	117.4	358.0	37.8	129.4	403.5
Duct	8.0	16.0	27.5	8.0	16.0	27.5	8.0	16.0	27.5
Pump	5.7	5.7	9.7	5.7	8.7	25.5	6.0	12.8	45.6
Piping	1.0	1.0	3.4	1.0	3.4	9.7	1.6	4.5	17.4
Instrumentation	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Stripper system									
Tower and trays (packing)	9.1	28.8	151.7	11.9	41.2	266.1	20.5	76.5	452.7
Pump	5.7	5.7	9.7	5.7	8.7	25.5	6.0	12.8	45.6
Piping	3.0	3.0	10.2	3.0	10.2	29.1	4.8	135	52.2
Instruments	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Heat exchangers									
Feed-effluent	11.5	55.1	308.1	52.3	290.2	1752.9	125.0	755.0	4560
Steam preheater	1.5	5.7	25.0	5.0	21.3	103.7	13.8	66.4	381.1
Stripper condenser	13.7	65.8	315.5	17.8	85.3	507.8	37.7	199.3	1204
Subtotal capital cost	152.1	450.4	1925	216.7	197.6	4006.3	339.0	1504	8185
Total capital cost (+30%)	197.7	585.5	2502.5	281.7	1037	5208	440.7	1955	10640

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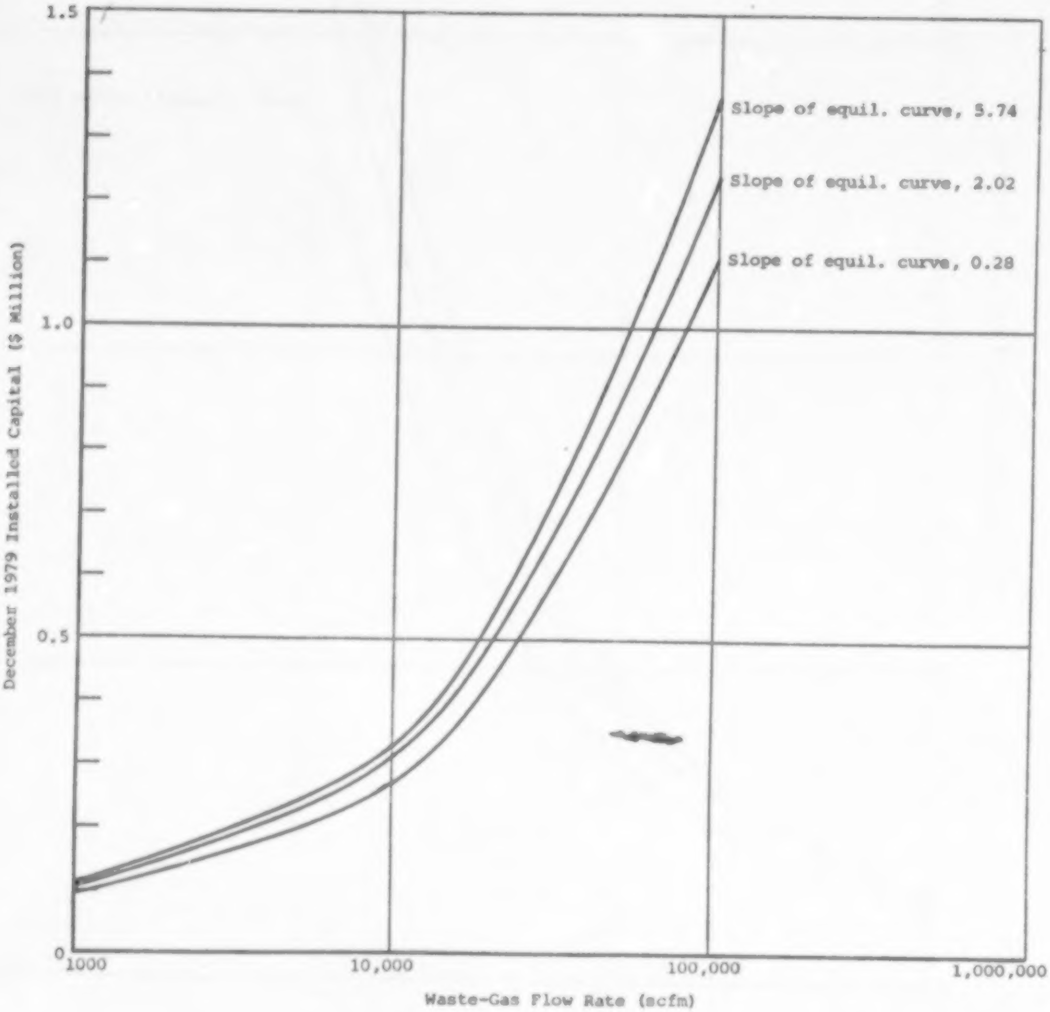

Fig. V-1. Installed Capital Cost vs Flow Rate for Complete Absorption System (No Stripper) with a VOC Removal Efficiency of 90.0%.

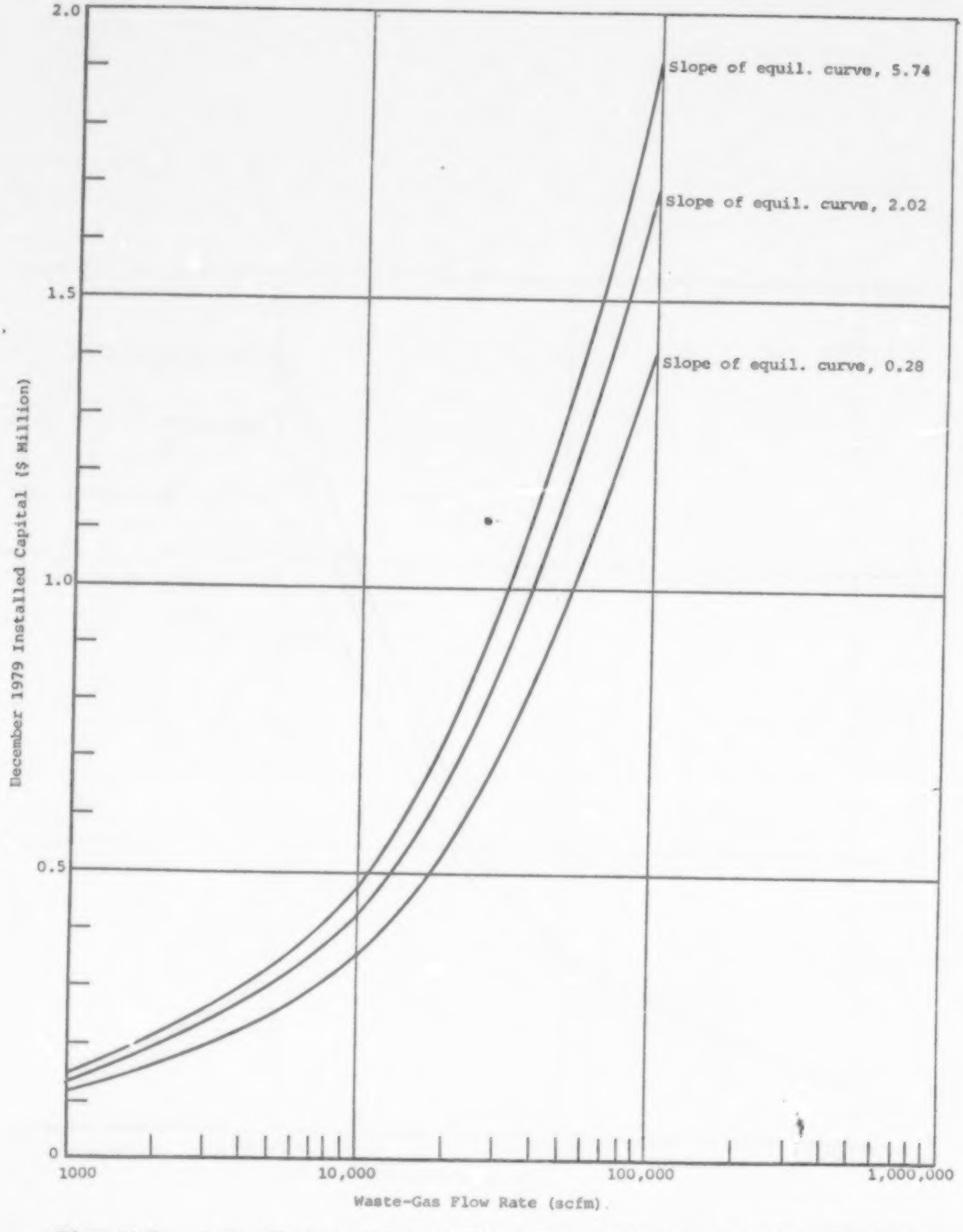

Fig. V-2. Installed Capital Cost vs Flow Rate for Complete Absorption System (No Stripper) with a VOC Removal Efficiency of 99.0%.

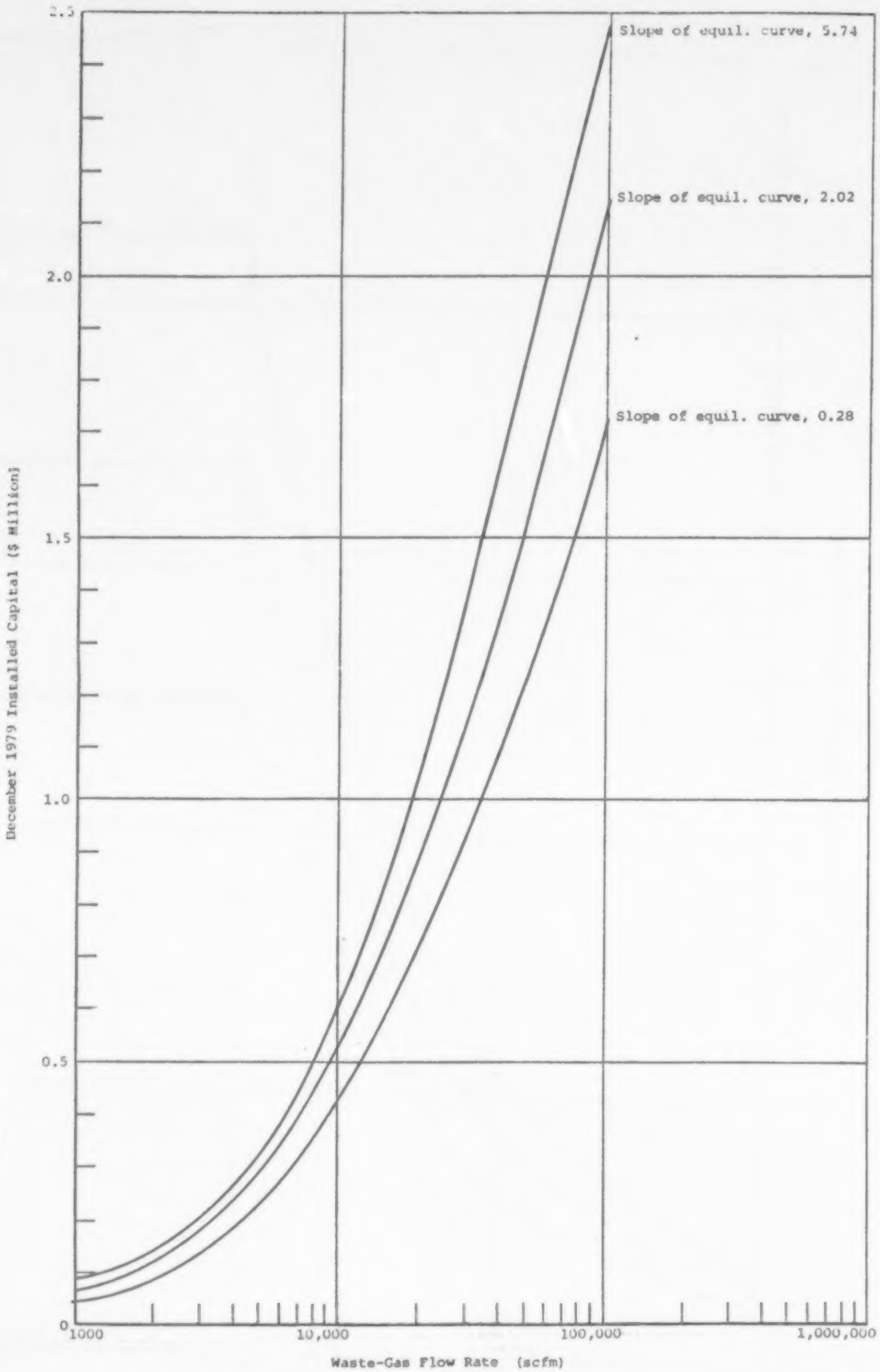

Fig. V-3. Installed Capital Cost vs Flow Rate for Complete Absorption System (No Stripper) with a VOC Removal Efficiency of 99.9%.

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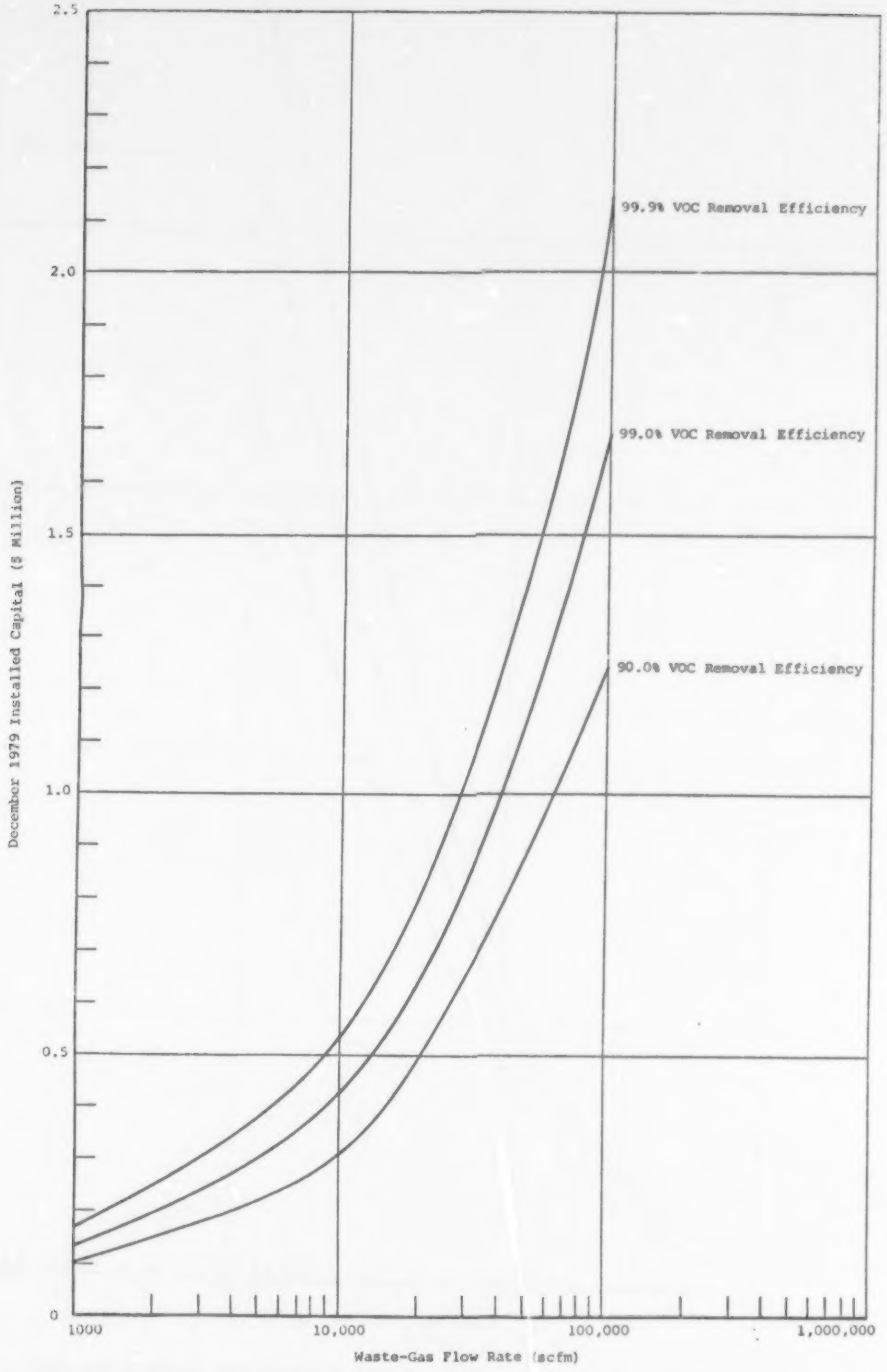

Fig. V-4. Installed Capital Cost vs Flow Rate for Complete Absorption System (No Stripper) with a Solute-Solvent System Having an Equilibrium Curve Slope of 2.0.

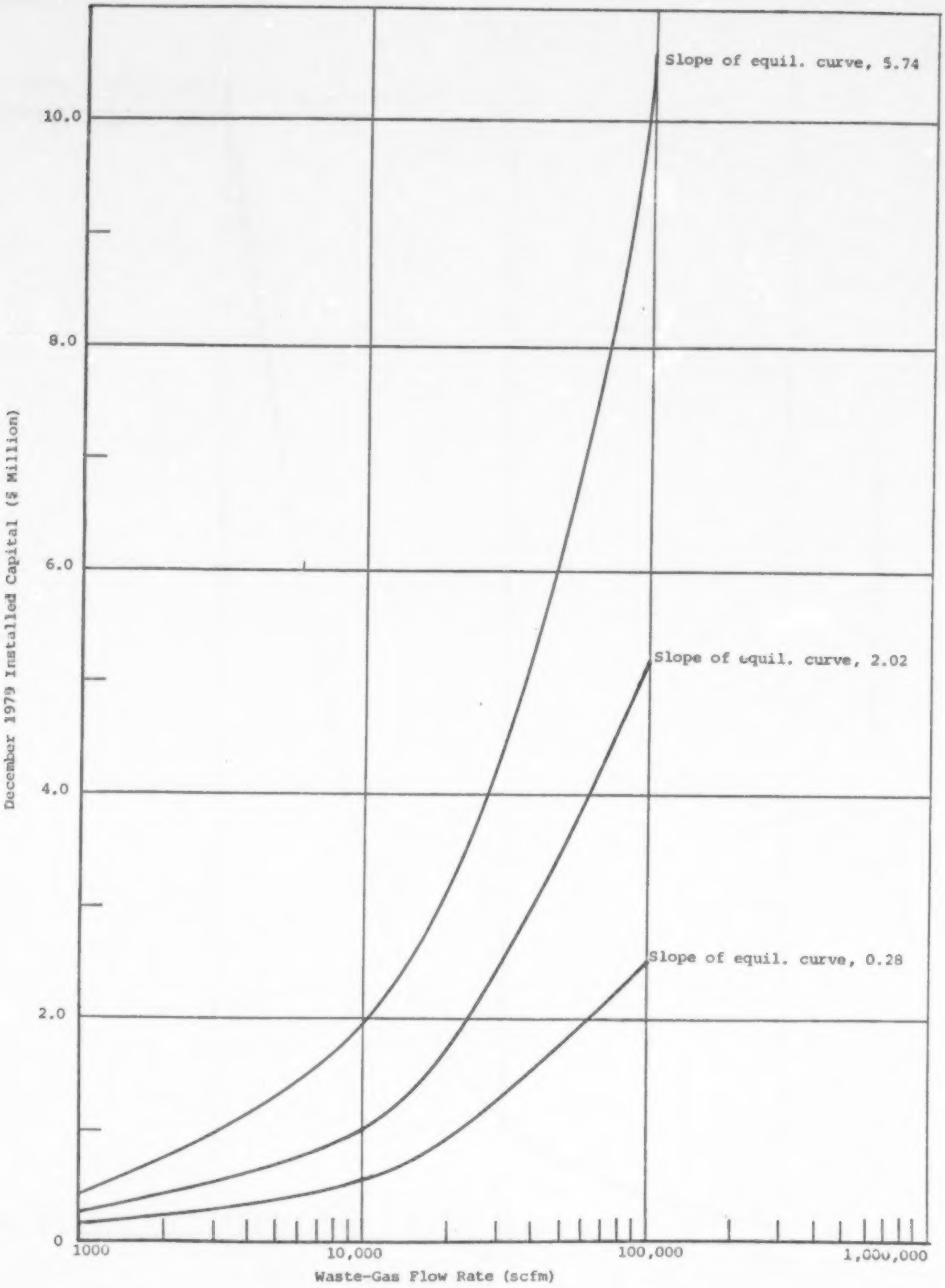

Fig. V-5. Installed Capital Cost vs Flow Rate for Complete Absorption and Stripping System with a VOC Removal Efficiency of 99.0%.

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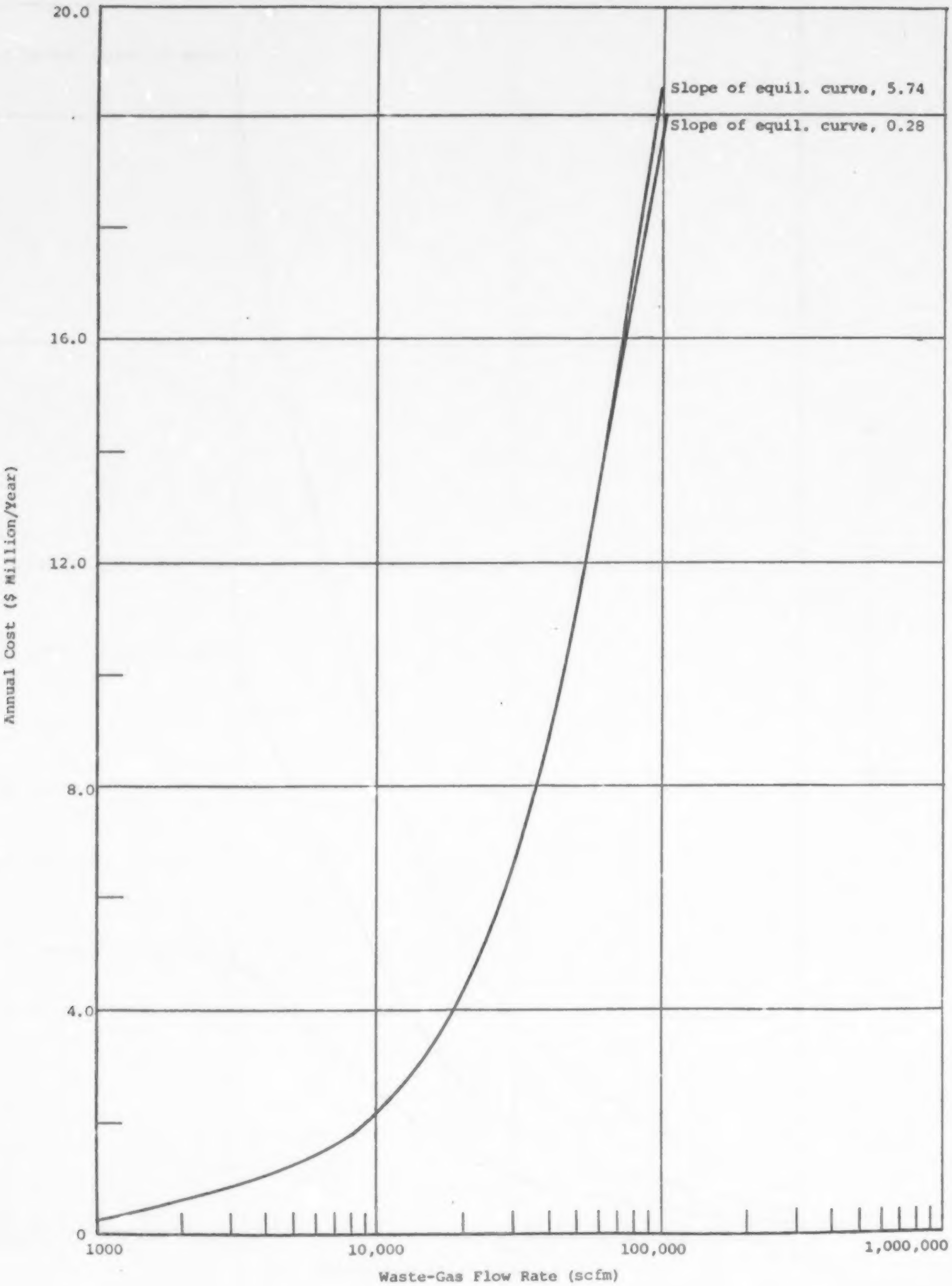

Fig. V-6. Annual Cost vs. Flow Rate for Absorber Only (No Stripper) with 5.0 wt % VOC in Waste Gas and 99% VOC Removal Efficiency.

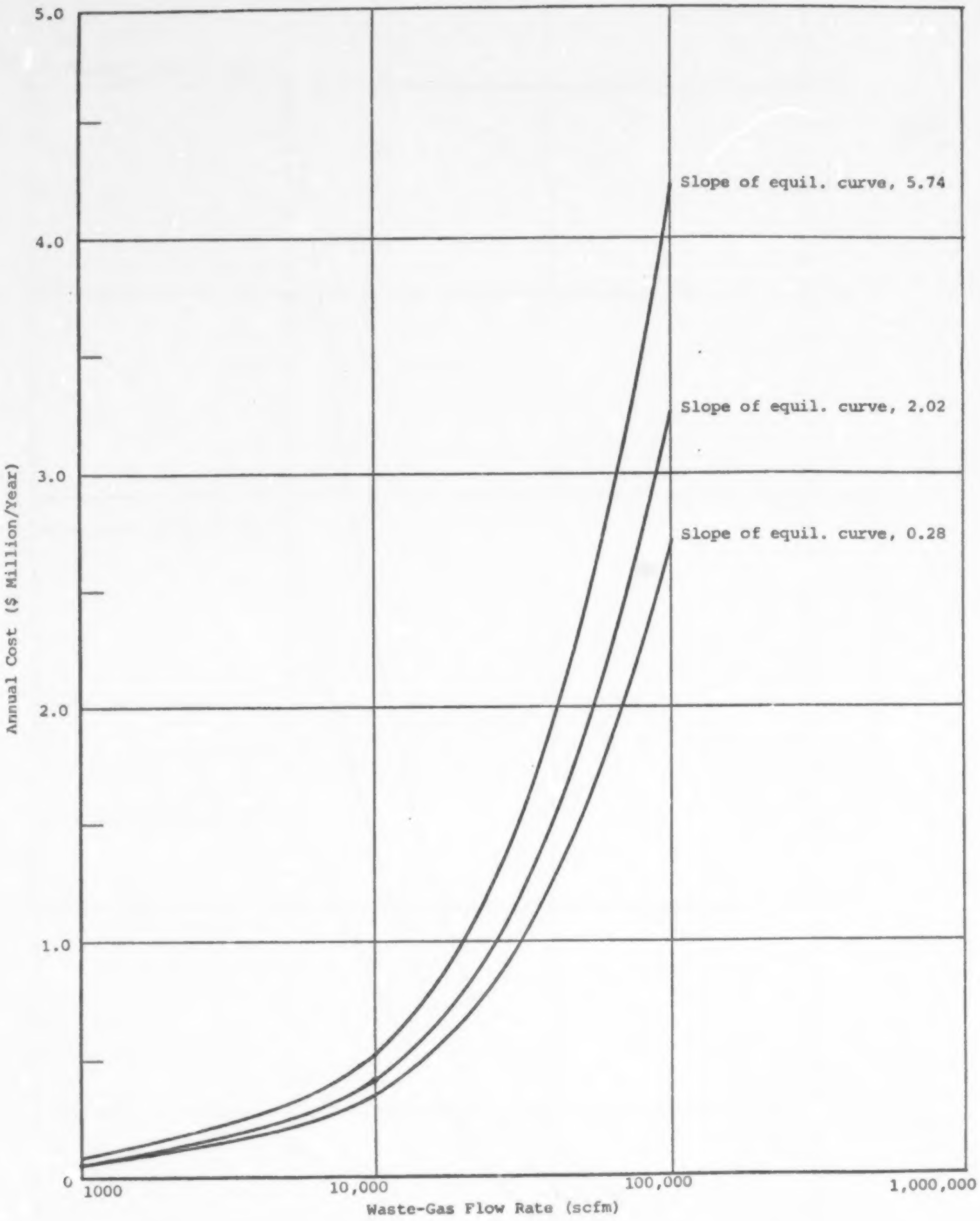

Fig. V-7. Annual Cost vs Flow Rate for Absorber Only (No Stripper) with 0.5 wt % VOC in the Waste Gas and 99% VOC Removal Efficiency.

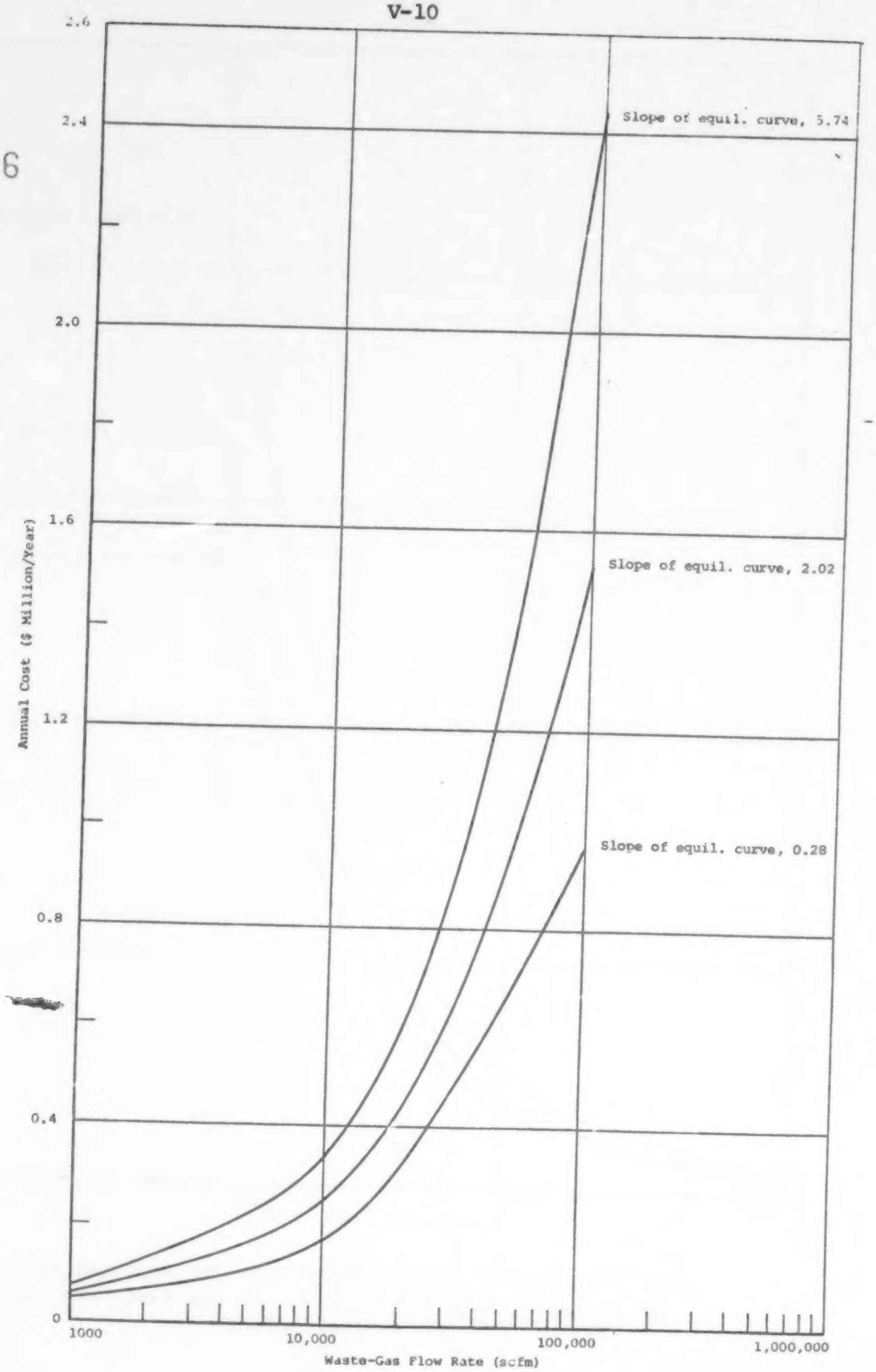

Fig. V-8. Annual Cost vs Flow Rate for Absorber Only (No Stripper) with 0.05 wt % VOC in the Waste Gas and a VOC Removal Efficiency of 99.0%

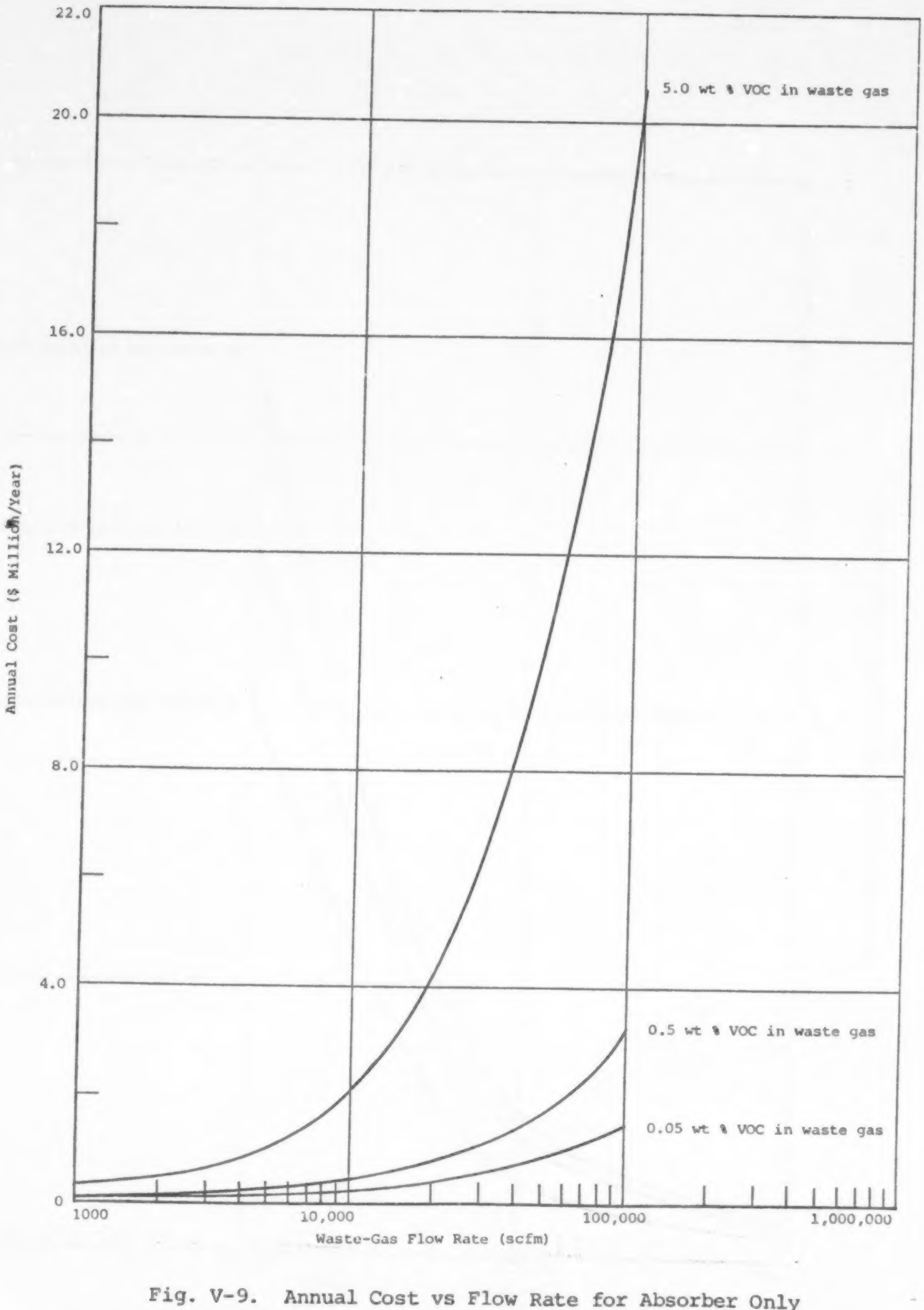

Fig. V-9. Annual Cost vs Flow Rate for Absorber Only (No Stripper) with a Solute-Solvent System Having an Equilibrium Curve Slope of 2.0 and 99% VOC Removal Efficiency.

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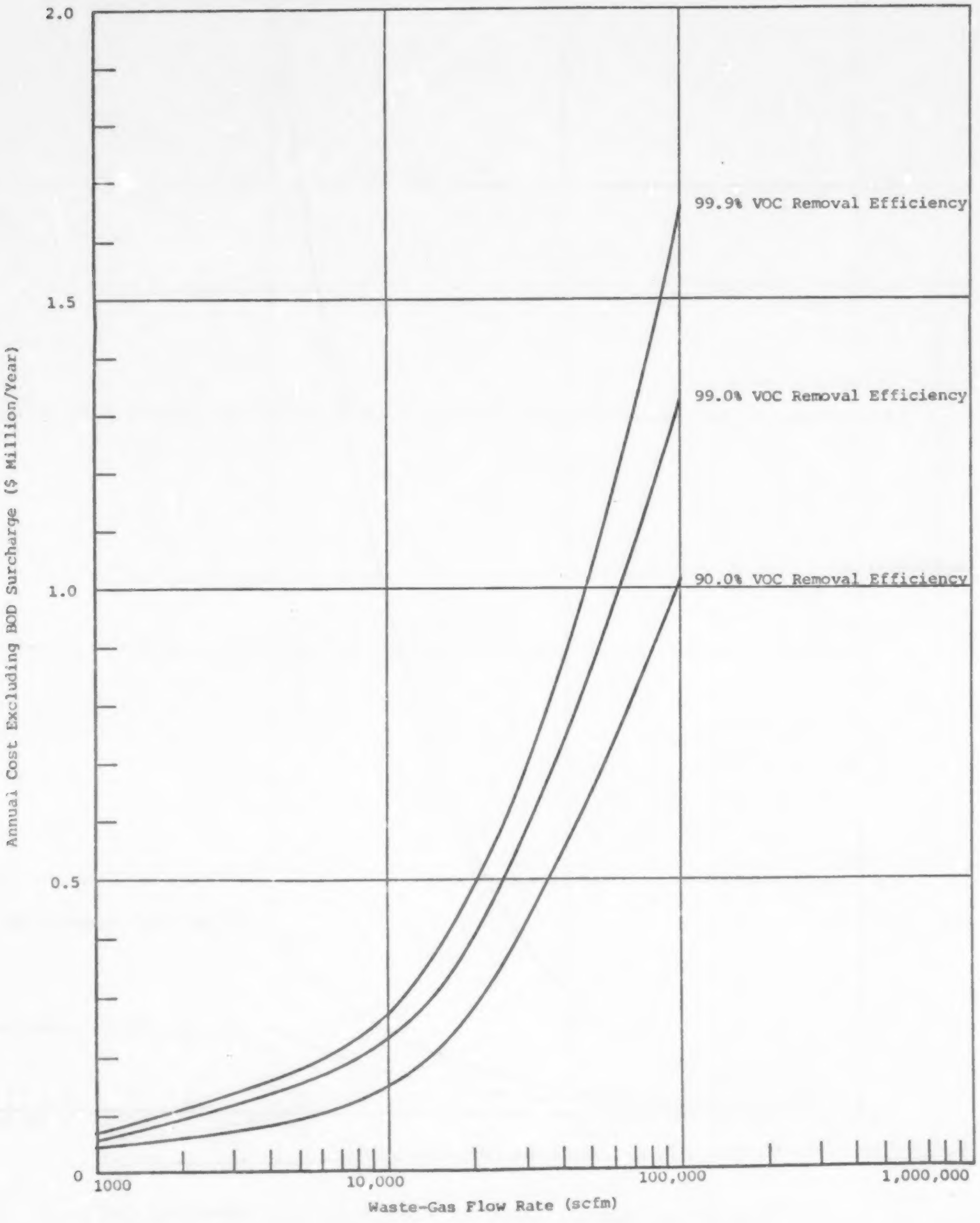

Fig. V-10. Annual Cost (Excluding BOD Surcharge) vs Flow Rate for Absorber Only (No Stripper) with a Solute-Solvent System Having an Equilibrium Curve Slope of 2.0.

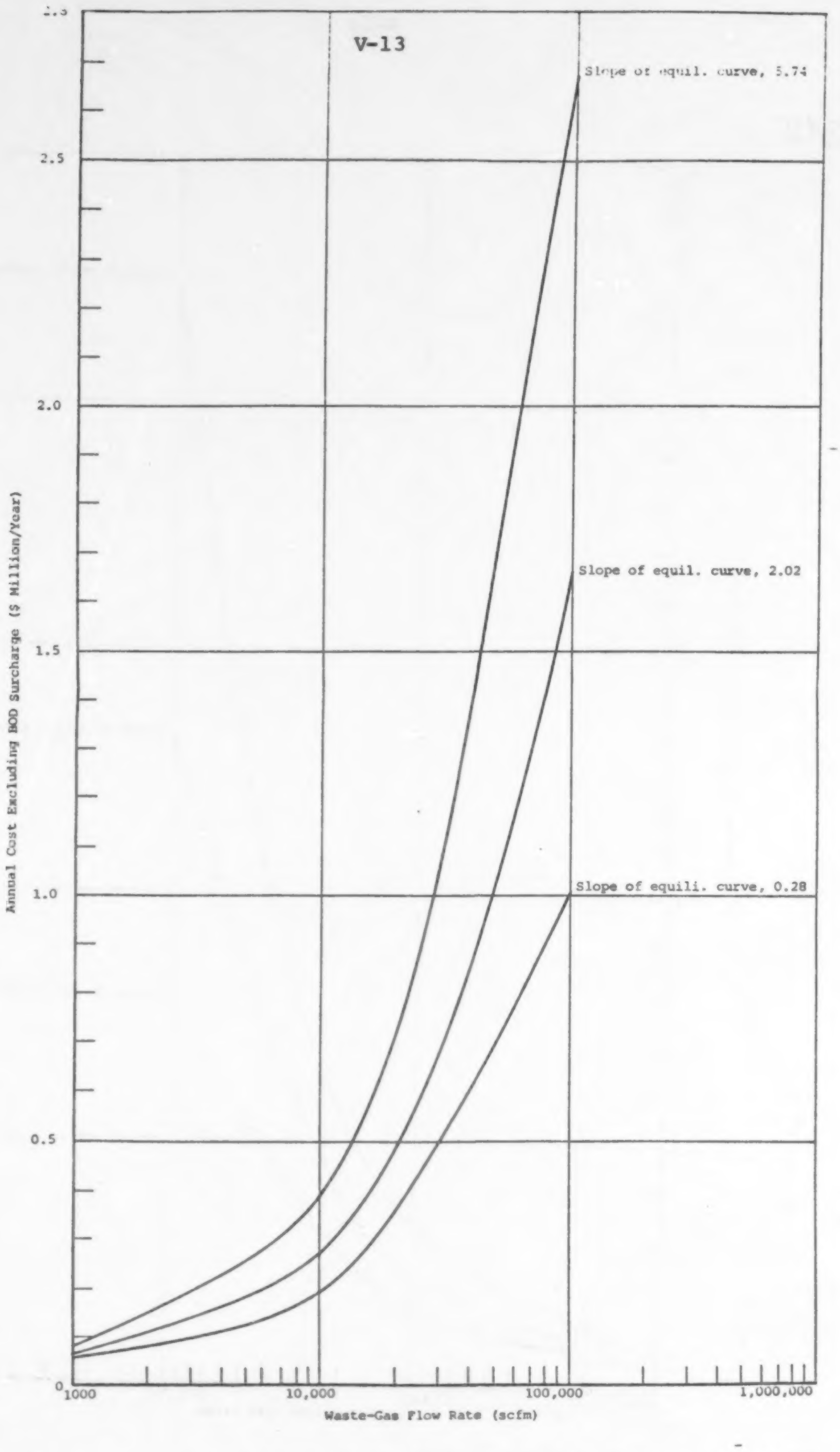

Fig. V-11. Annual Cost (Excluding BOD Surcharge) vs Flow Rate for Absorber Only (No Stripper) with 99.9% VOC Removal Efficiency.

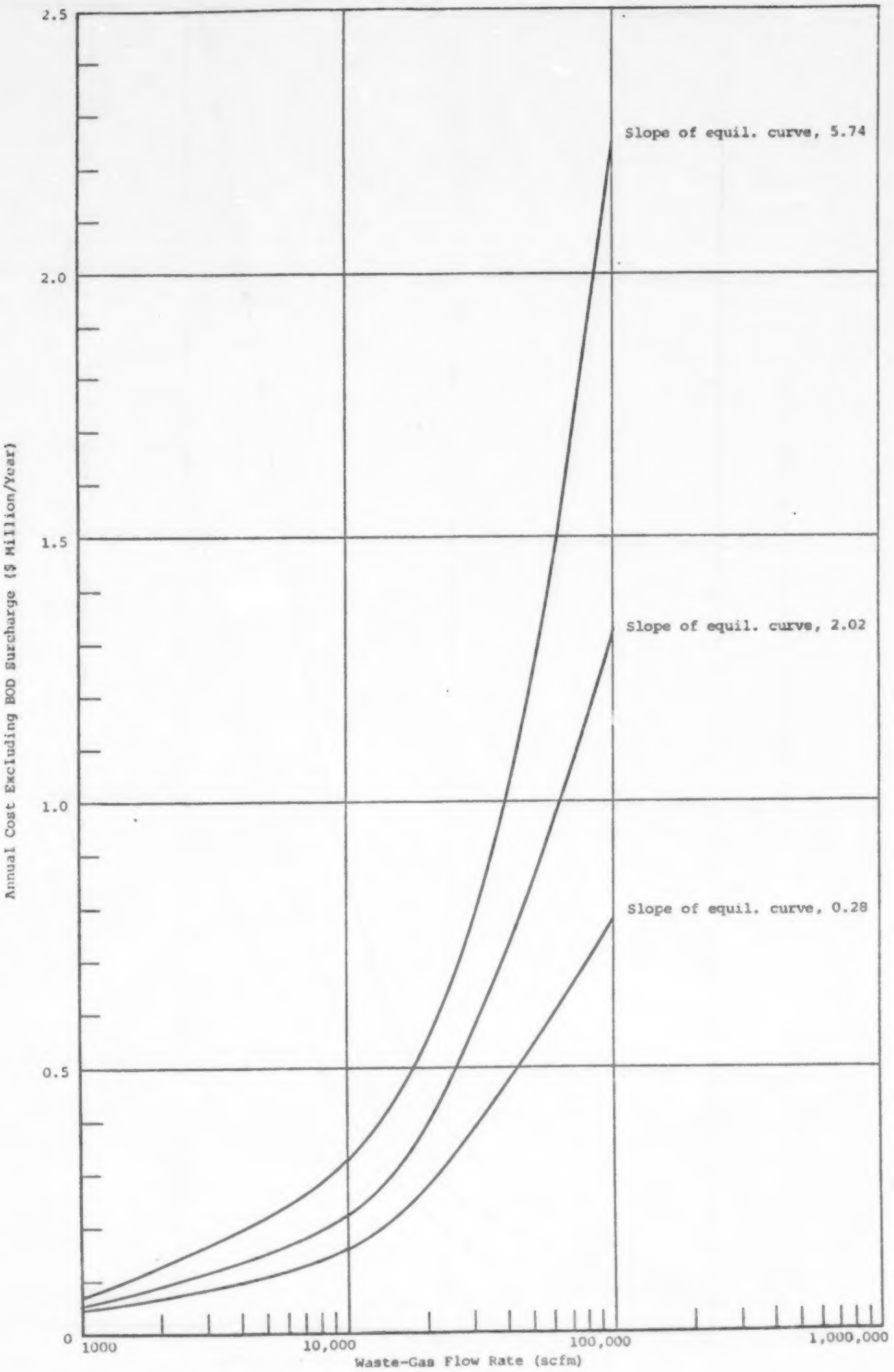

Fig. V-12. Annual Cost (Excluding BOD Surcharge) vs Flow Rate for Absorber Only (No Stripper) with 99% VOC Removal Efficiency.

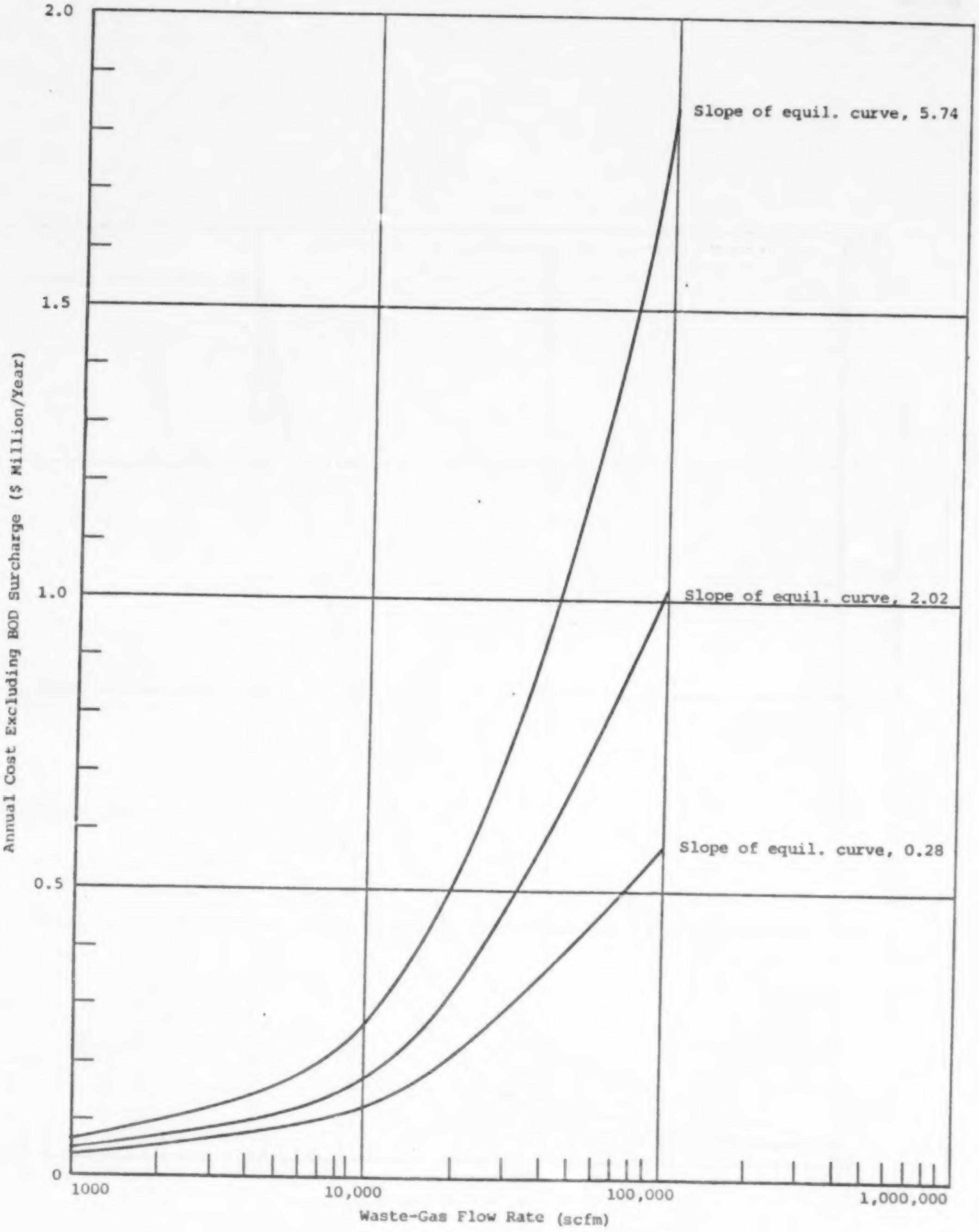

Fig. V-13. Annual Cost (Excluding BOD Surcharge) vs Flow Rate for Absorber Only (No Stripper) with 90% VOC Removal Efficiency.

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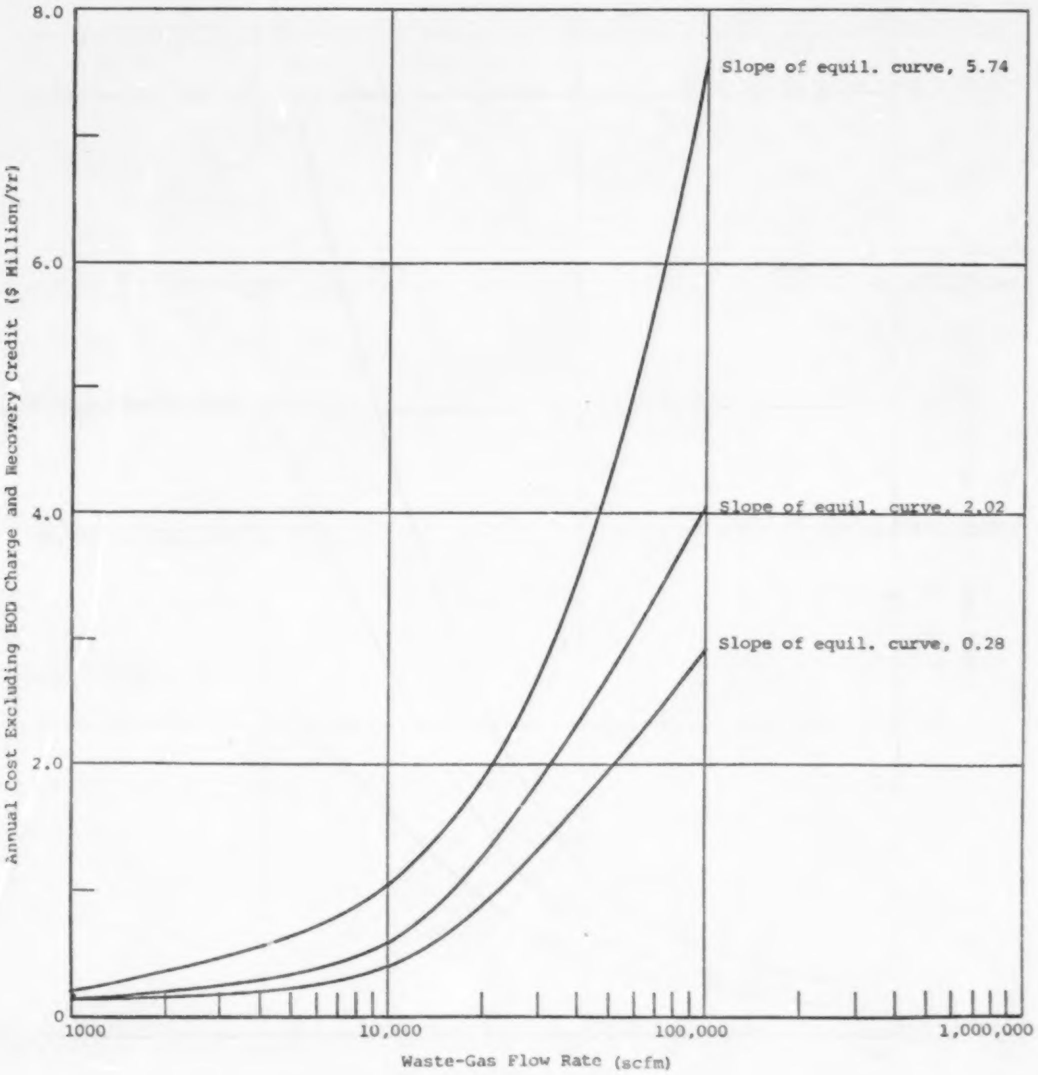

Fig. V-14. Annual Cost (Excluding BOD Charge and VOC Recovery Credit) vs Flow Rate for Absorber and Stripper with 99.0% VOC Removal Efficiency.

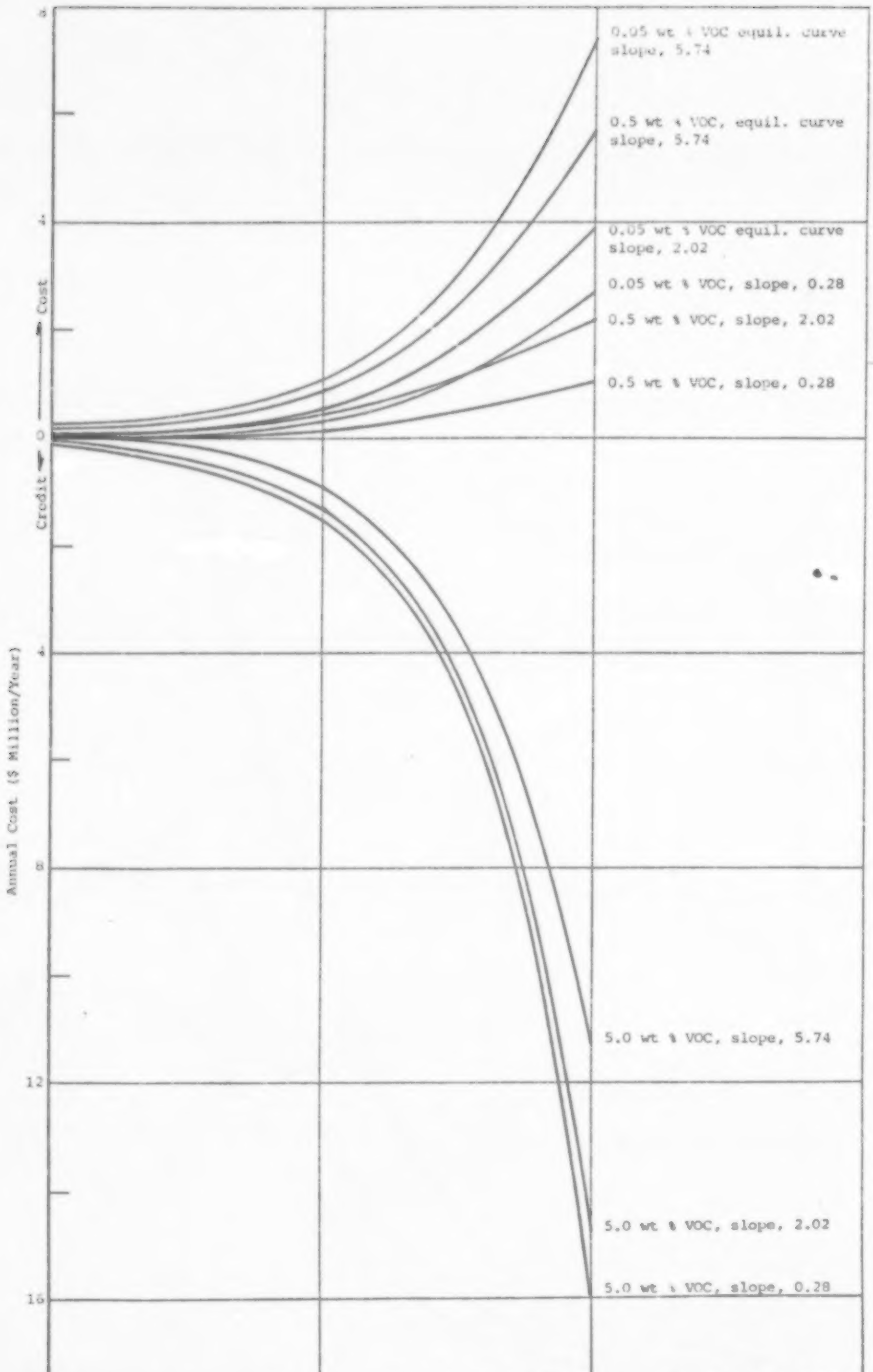

Fig. V-15. Annual Cost vs Flow Rate for Absorber and Stripper with 99% VOC Removal and $0.10/lb Credit for Recovered VOC.

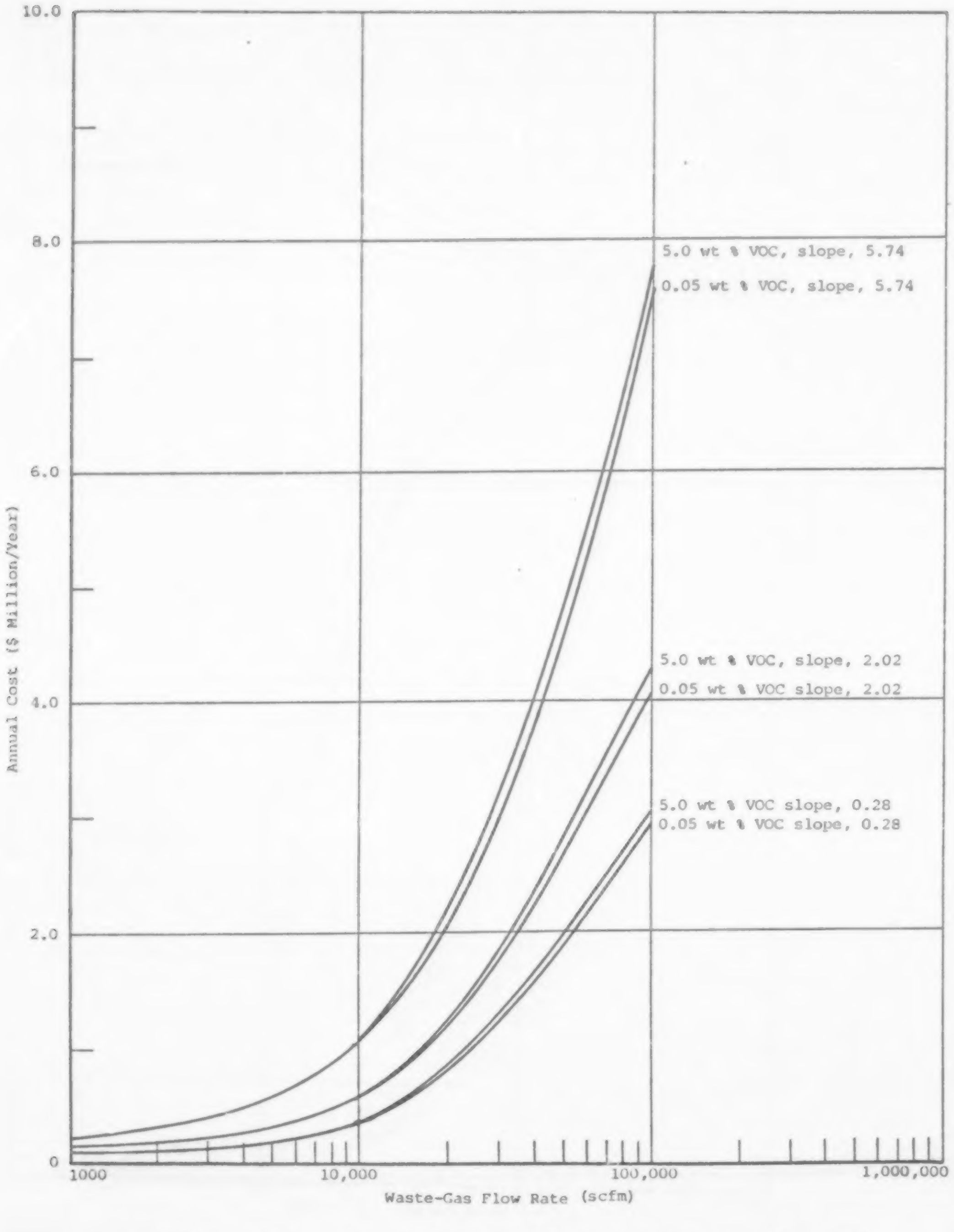

Fig. V-16. Annual Cost vs Flow Rate for Absorber and Stripper with 99% VOC Removal and Zero Credit for Recovered VOC.

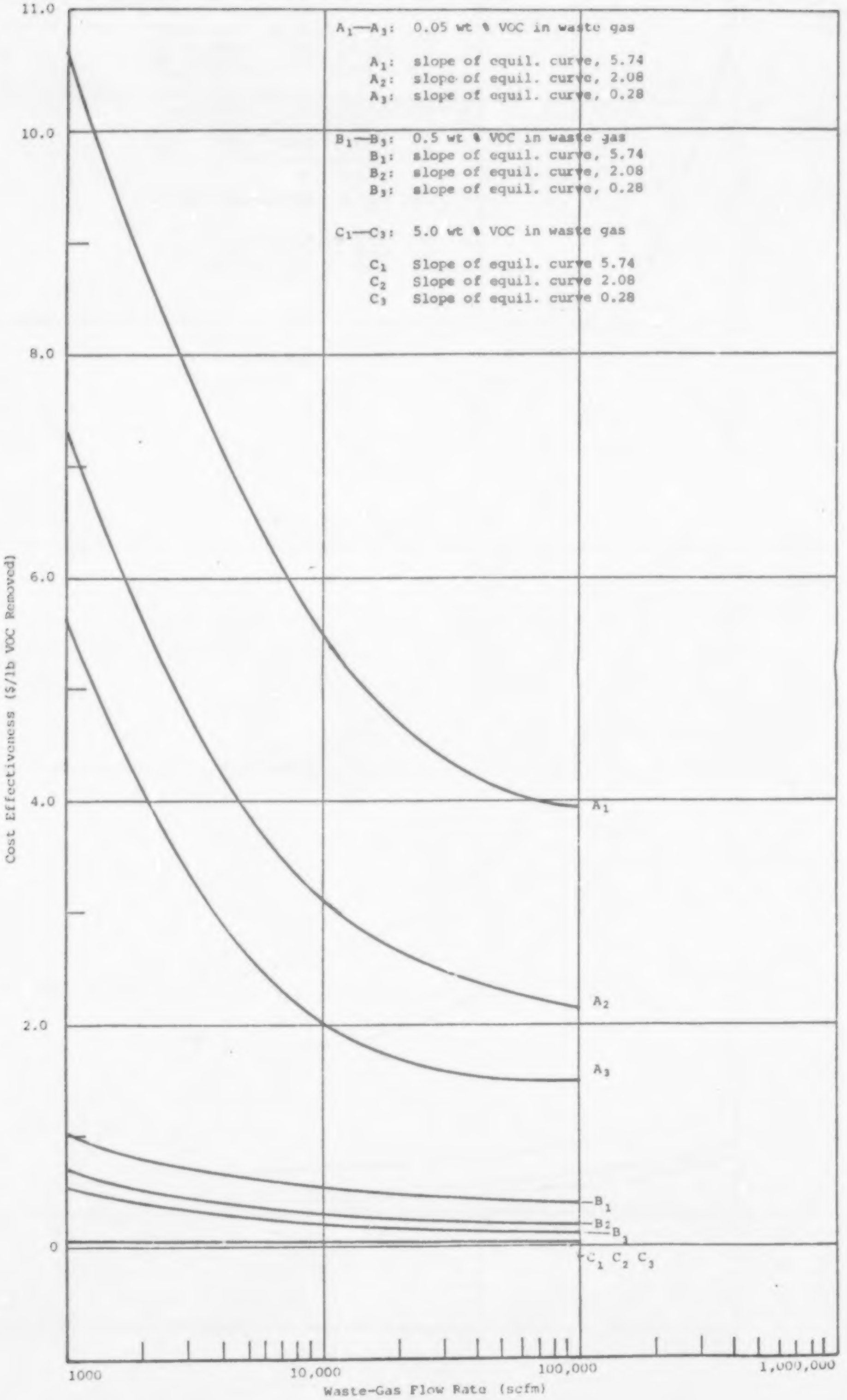

Fig. V-17. Cost Effectiveness vs Flow Rate for Absorber and Stripper with 99% VOC Removal and Zero Credit for Recovered VOC

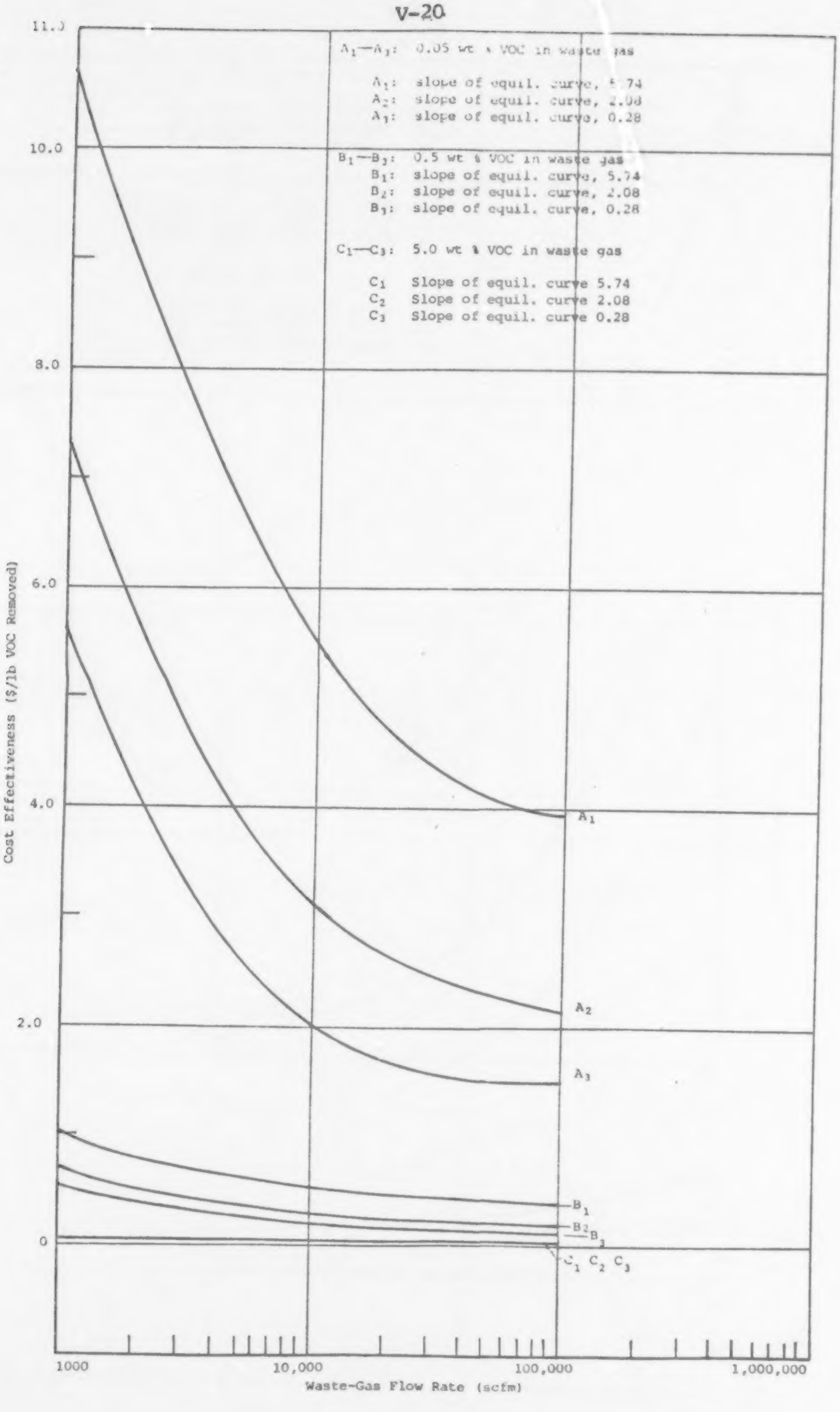

Fig. V-18. Cost Effectiveness vs Flow Rate for Absorber and Stripper with 99% VOC Removal Efficiency and $0.10/lb Credit for Recovered VOC.

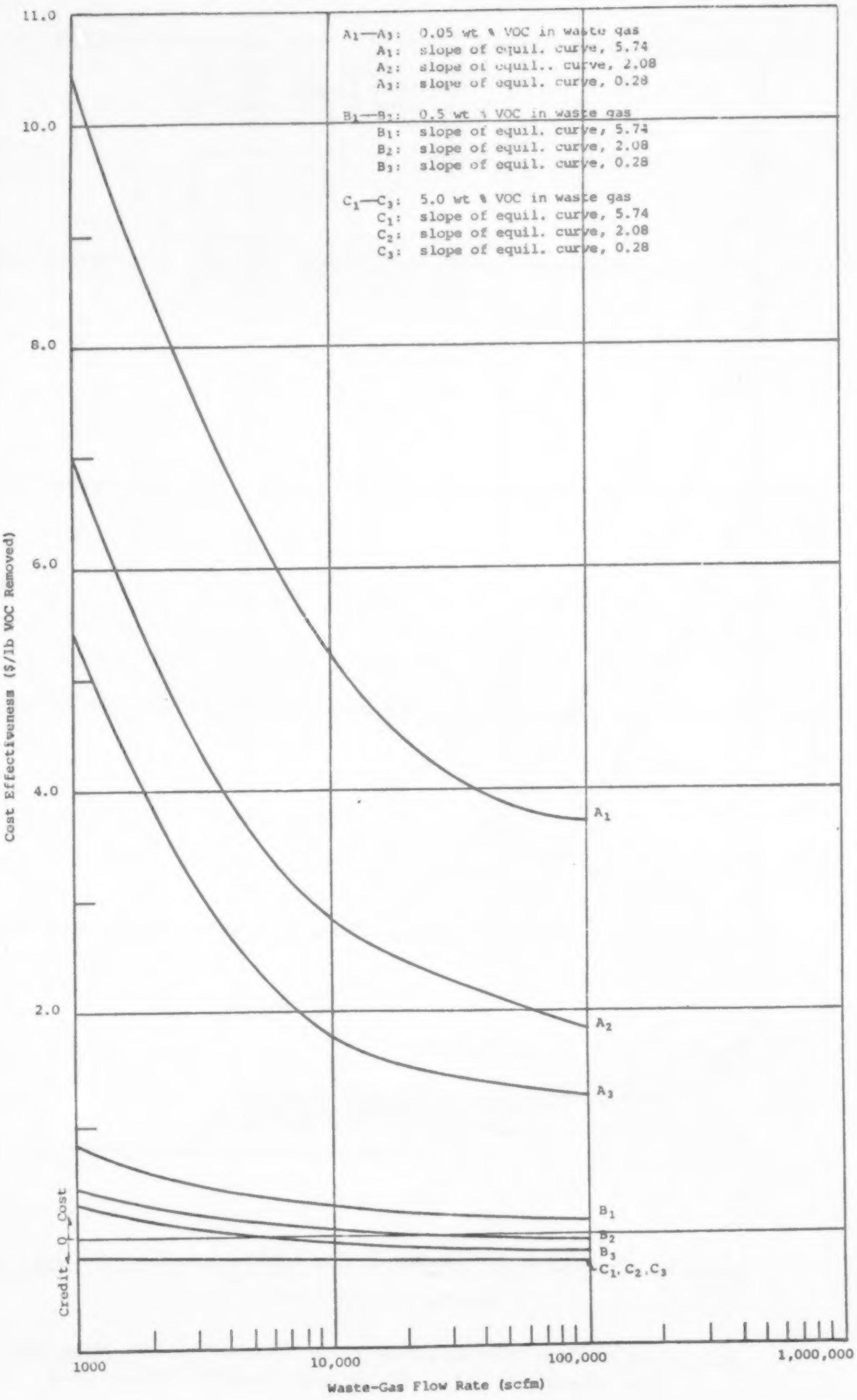

Fig. V-19. Cost Effectiveness vs Flow Rate for Absorber and Stripper with 99% VOC Removal Efficiency and $0.20/lb Credit for Recovered VOC.

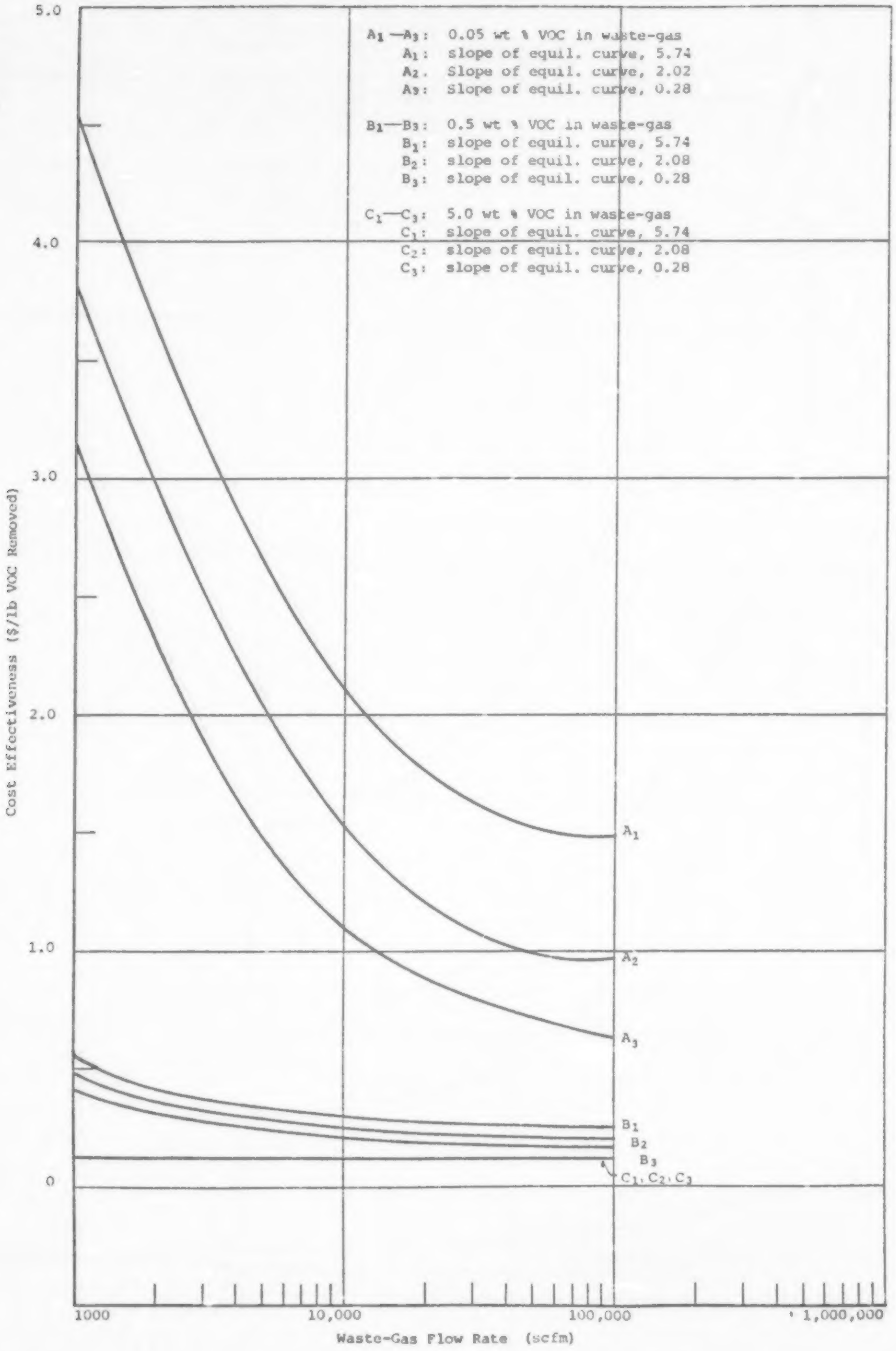

Fig. V-20. Cost Effectiveness vs Flow Rate for Absorber Only (No Stripper) with 99.9% VOC Removal Efficiency.

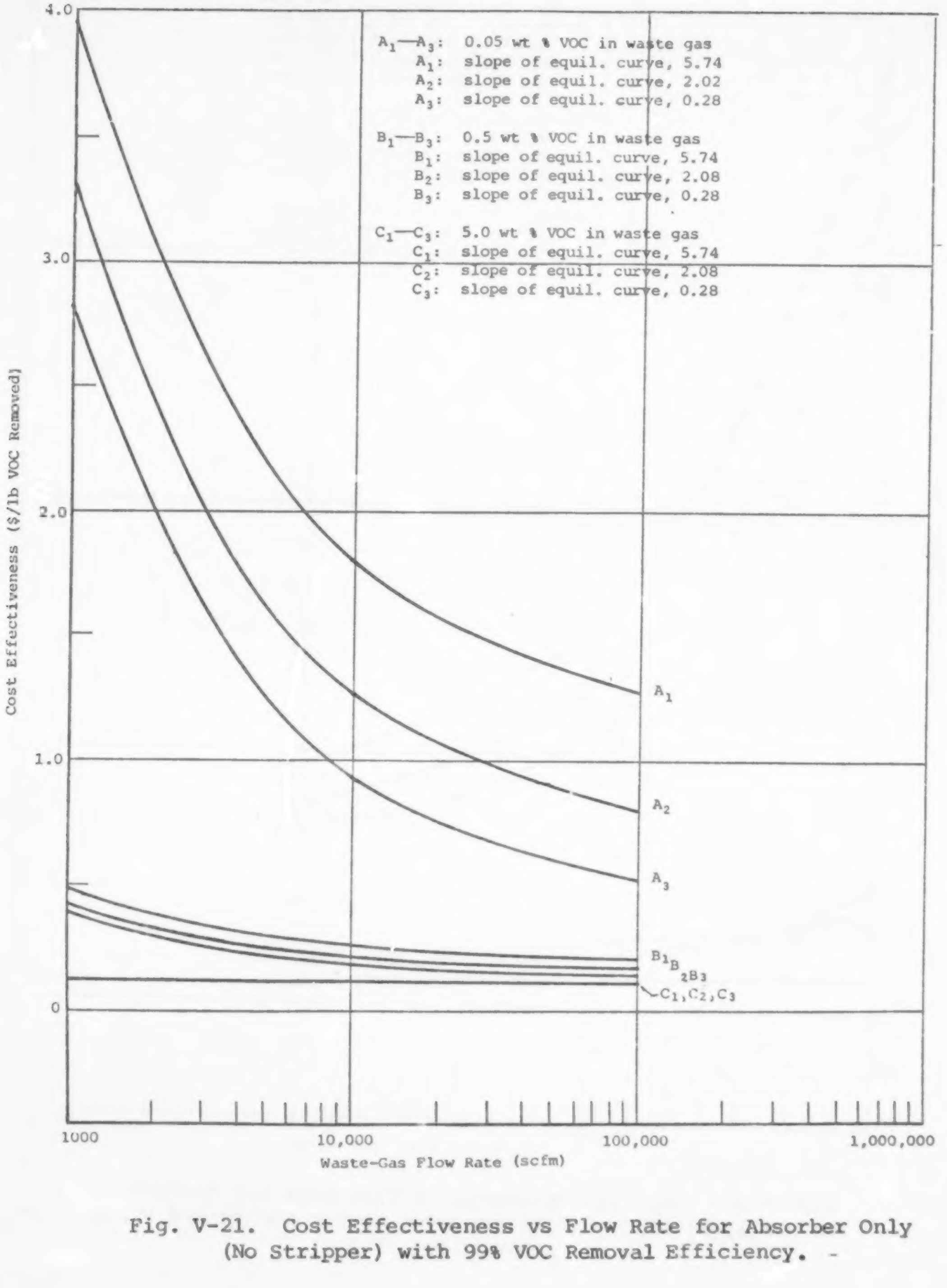

Fig. V-21. Cost Effectiveness vs Flow Rate for Absorber Only (No Stripper) with 99% VOC Removal Efficiency. -

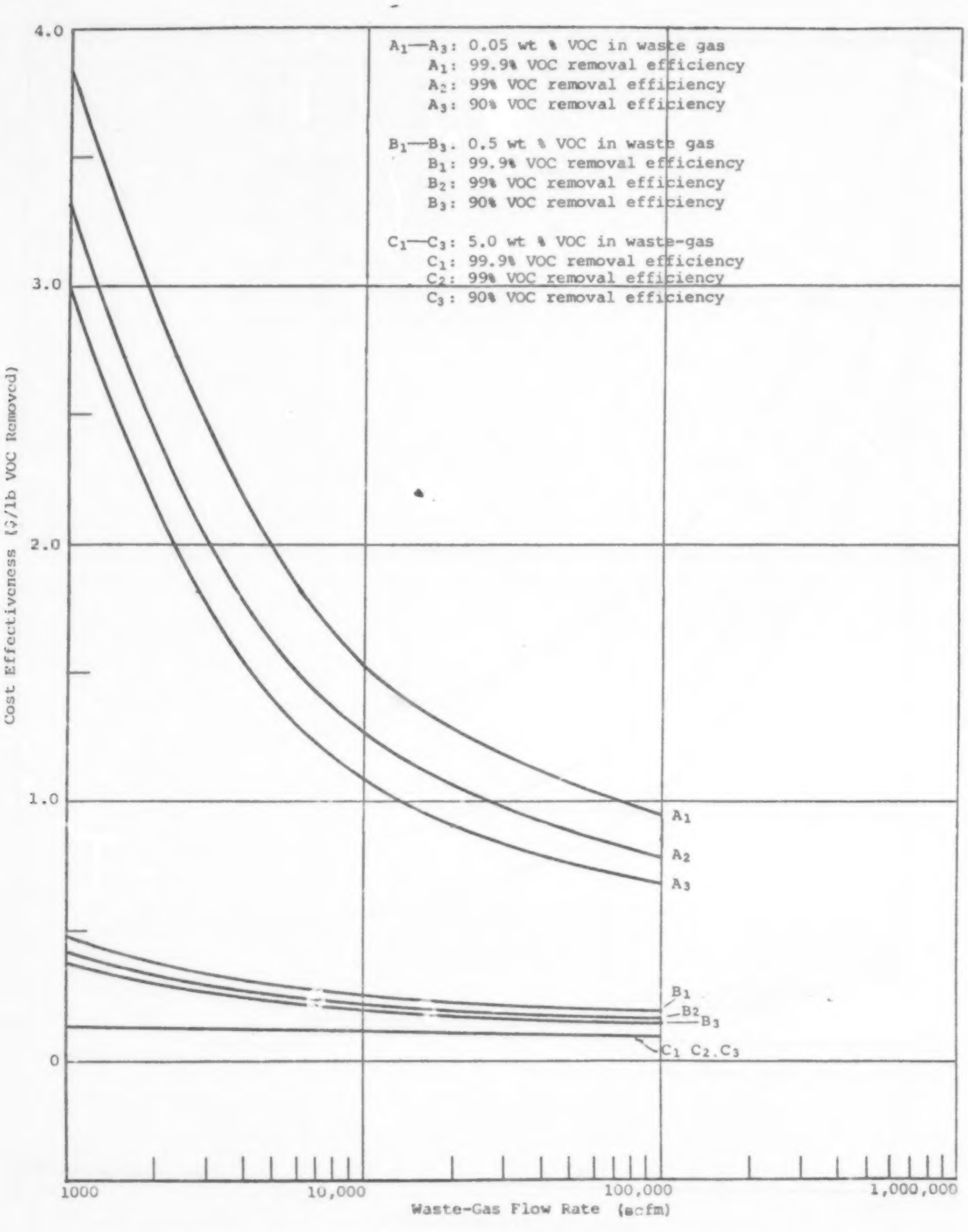

Fig. V-22. Cost Effectiveness vs Flow Rate for Absorber Only (No Stripper) with a Solute-Solvent System Having and Equilibrium Curve Slope of 2.0.

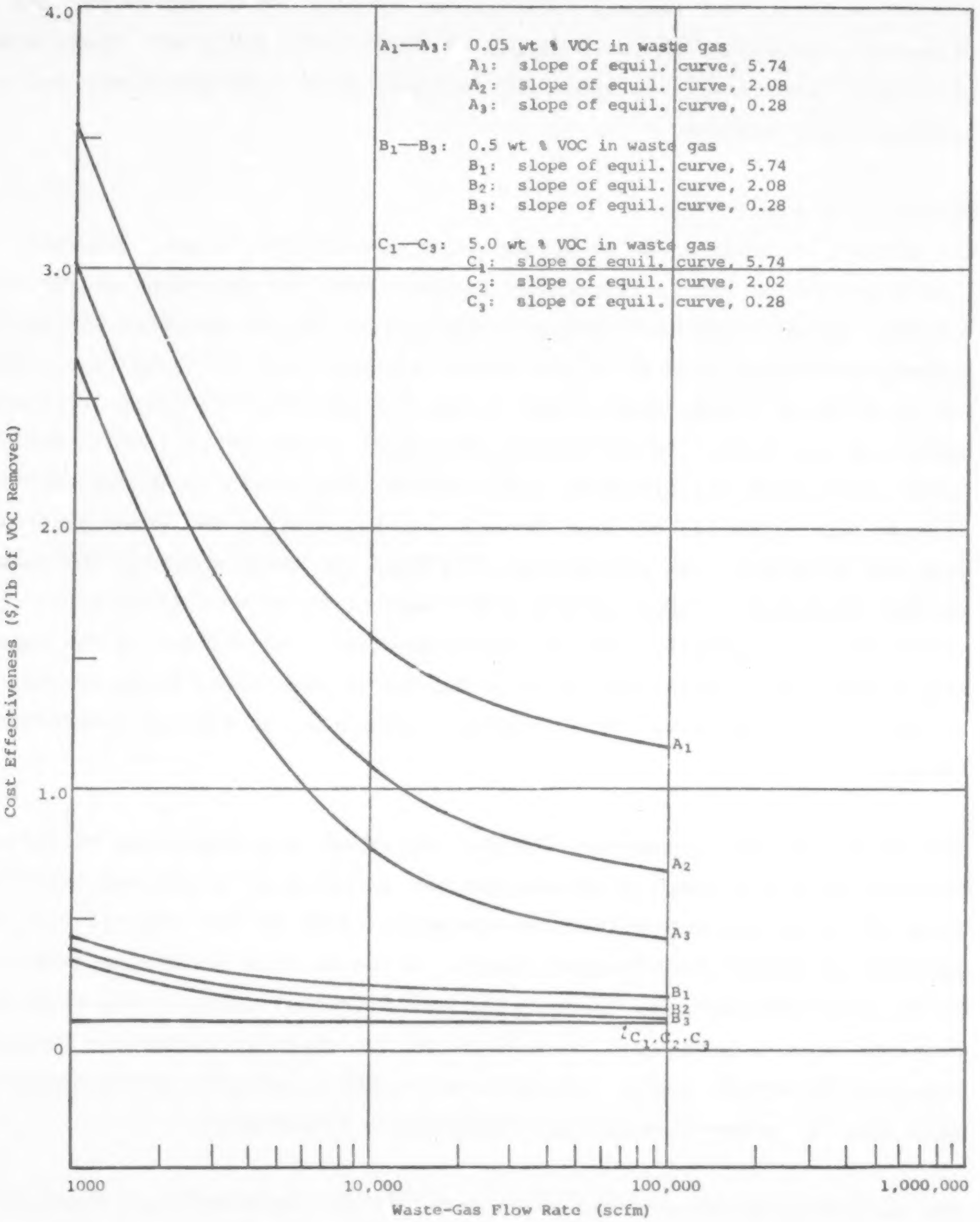

Fig. V-23. Cost Effectiveness vs Flow Rate for Absorber Only (No Stripper) with 90% VOC Removal Efficiency.

Costs were developed for both models for gas flow rates of 1,000, 10,000, and 100,000 scfm, for VOC removal efficiencies of 90.0, 99.0, and 99.9%, and for values of m (equilibrium curve slope) of 0.28, 2.02, and 5.74. These slopes correspond respectively to those for methanol-water, acetone-water, and acetaldehyde-water systems.

3. Criteria and Limitations

The primary absorption and stripping tower parameters (height, diameter, and liquid/gas ratio) and corresponding capital costs are dependent on the individual vapor/liquid equilibrium relationships for the specific VOC-solvent systems and cannot readily be presented in simple generic terms (i.e., expressed in terms of simply defined and measurable physical, chemical, or thermodynamic properties). To illustrate the effect of the variations in the vapor/liquid equilibrum relationships and to permit the curves to be used for order-of-magnitude estimates of costs for VOC-solvent systems for which vapor/liquid data are available, the curves were developed for three specific VOC-solvent systems that span a comparatively wide range of relative volatilities: methanol-water, acetone-water, and acetaldehyde-water. The effect of the vapor/liquid equilibrium relationship is presented in simplified terms as the slope of the equilibrium curve for very dilute solutions, at ambient temperature and pressure.

The estimated tower parameters (height, diameter, and liquid/gas ratio) were obtained by use of simplified calculations in which it is assumed that the value of m is constant within the operating range of the tower (i.e., the equilibrium curves are straight lines). Although this assumption generally holds reasonably well for dilute solutions, rigorous calculations requiring complete vapor-liquid equilibrium data for the specific system are generally required for actual design calculations; so the cited cost curves should be used only for order-of-magnitude estimates or comparisons.

The calculated absorber-tower parameters (height, diameter) are based on a value of 0.7 for mG_M/L_M. This value, although commonly assumed in making first-pass design calculations for economic studies, is not necessarily optimum. Optimum design requires the balancing of mG_M/L_M with the corresponding required tower parameters for minimum overall cost.

Cost calculations and the corresponding curves were based on the following criteria for selecting the type of tower to be used (packed or tray): a diameter of less than 2 ft for packed towers and a diameter of greater than 4 ft for tray towers. When tower diameters between 2 and 4 ft were required, cost calculations were made for both types of towers and the lower cost alternative was used.

All equipment cost estimates were based on the use of carbon-steel construction throughout. For applications in which corrosive conditions are present (vapor or solvent) corrosion-resistant construction materials may be required, with correspondingly higher capital costs. Other criteria used in the selection of equipment parameters and cost estimates are the following:

a. Towers——Tray spacing, 18 in.; packing, 1-in. porcelain Raschig rings; overall height for <2.5-ft-diam towers, add 4X diameter to tray or packed tower height; for 2.5- to 4-ft-diam towers, add 3X diameter; for >4-ft-diam towers, add 2X diameter; operating pressure, atmospheric (50 psig design pressure).

b. Inlet Duct——Carbon steel, 150-ft long, 1/8 in. in wall thickness, flanged, 4 ells, 1 damper or valve and control, 1 expansion joint.

c. Piping——Welded carbon-steel pipe with normal number of fittings per 100 ft.

d. Blowers (Compressors)——Electric drive; installation complete, including inter- and after-coolers if required; includes prorata building if required.

e. Pumps——Ductile iron, single-stage centrifugal pumps; includes 200 ft of conduit run, standard valving, and 100 ft of steel suction plus discharge piping.

f. Heat Exchangers——Carbon steel, 150-psig, fixed tube sheet; 1-in. tubes 8 ft long; piping, same materials as tubes and shell, includes foundation or share of structure.

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4. System Variations

a. General——The most common variations from the model absorption systems include the use of organic liquids as solvents, the use of refrigerated coolers or condensers, the use of vacuum stripping, and requirements for corrosion-resistant materials. These variations and their effects on costs and cost effectiveness are discussed briefly in the following sections.

b. Organic Solvents——Absorption systems that are used for the removal of VOC components having low water solubilities typically require the use of organic solvents. The contained VOC is generally stripped from the solvent and the solvent is recycled to the absorber (see Fig. II-6). Capital and operating costs are generally somewhat higher than for the model systems because of the following factors:

1. More complete stripping is usually required, resulting in higher stripper capital costs and/or steam requirements.
2. The solvent usually must be cooled to a lower temperature before recycle, requiring greater heat exchanger capacity and cooling water usage than when the solvent is discharged.
3. Solvent losses in the outlet gas must be much lower, which may require greater absorber capacity and possibly refrigerated cooling of the solvent.
4. Solvent unit costs are higher.
5. Residual VOC in the solvent recycled to the absorber will require higher solvent usage and/or higher absorber capacity than with once-through solvent usage for the same absorber VOC removal efficiency.

c. Refrigerated Coolers and Condensers——Mechanical refrigeration equipment may be required to attain temperatures necessary for adequate solubility of VOC in the solvent and/or to minimize the loss of organic solvent from the absorber or the stripper. Cost data on refrigerated systems are presented in a separate report.[1] Requirements for refrigerated coolers or condensers will usually result in higher capital and operating costs because of the following factors:

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[1] D. G. Erikson, Control Device Evaluation. Condensation (July 1980) (EPA/ESED report, Research Triangle Park, NC).

1. The cost of refrigeration compressors and auxiliary equipment (i.e., condensers, heat exchangers) will increase capital costs significantly.
2. The power required for compression will increase operating costs.

d. Vacuum Stripping—Vacuum stripping is frequently used as an alternative to steam stripping for reducing VOC concentration in wastewater. The generally higher capital costs of vacuum stripping systems (e.g., additional costs of vacuum-producing equipment, larger-diameter towers) may be offset by lower operating costs resulting primarily from a reduction in steam requirements. Vacuum stripping may also be preferable when VOC components that have high boiling points are stripped.

e. Corrosion-Resistant Materials—Corrosive conditions requiring the use of special corrosion-resistant materials will usually result in significantly higher capital costs compared to the cost of carbon steel equipment. Corrosive conditions occur most frequently in absorption systems used for VOC emission control when the VOC components include halogenated organic compounds, organic acids, and amines and in systems that provide concurrent scrubbing of corrosive inorganic components (e.g., inorganic acid vapors, acid, and salt particulates).

A few of the many specific materials used for corrosion control include a variety of stainless steels, Monel®, the Hastelloys®, nickel, and a variety of plastics used for the fabrication or lining of equipment and piping. Comparative capital costs for condensers fabricated from Monel, type 304 stainless steel, and carbon steel are presented in a separate report.[1] These costs exemplify the effect that special material requirements may have on capital costs.

B. ANNUAL COSTS

Annual costs for various operating conditions are presented in Appendix A. These costs were the basis for all the cost-effectiveness graphs included in the report. The basis used in calculating annual costs is defined in Table V-2.

Table V-2. Annual Cost Parameters

Operating factor	8760 hr/yr[a]
Operating labor	$15/man-hour
Fixed costs	
Maintenance labor plus materials, 6%	29% installed capital
Capital recovery, 18%[b]	
Taxes, insurances, administrative charges, 5%	
Utilities	
Electric power	$0.03/kWh
Steam	$2.50/M̄ Btu
Wastewater treatment	$0.25/1000 gal + $0.10/lb of BOD
Cooling water	$0.10/1000 gal

[a] Process downtime is normally expected to range from 5 to 15%. If the hourly rate remains constant, the annual production and annual VOC emissions will be correspondingly reduced. Control devices will usually operate on the same cycle as the process. From the standpoint of cost-effectiveness calculations, the error introduced by assuming continuous operation is negligible.

[b] Based on 10-year life and 12% interest.

C. COST EFFECTIVENESS AND ENERGY EFFECTIVENESS

The cost effectivenss and energy effectiveness are calculated by dividing the annual cost for a particular option (Appendix A) or energy consumption (e.g., steam or electric power) by the total annual amount of VOC, with the assumed removal efficiencies.

Typical cost-effectiveness values are given in Table V-3, and the corresponding values for energy effectiveness are presented in Table V-4. Additional cost-effectiveness values for other conditions are given in Appendix A. Values for other conditions that are not given in the cited tables or graphs can be determined by the methods described in Appendix B.

Table V-3. Cost Effectiveness Summary

Absorber Conditions: VOC removal, 99%; $L_M/mG_M = 1.4$.
Stripper Conditions: Organic removal, 99%; steam ratio = 0.2 mole of steam/mole of air in.

	Cost Effectiveness (10^3 \$/Mg of VOC) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
Operating Parameters	1.0	10	100	1.0	10	100	1.0	10	100
VOC recovery credit = 0 for air containing									
0.05 wt % VOC	12.4	4.41	3.34	16.1	6.78	4.66	23.6	12.1	8.71
0.50 wt % VOC	1.24	0.44	0.34	1.61	0.68	0.47	2.36	1.21	0.87
5.0 wt % VOC	0.13	0.046	0.036	0.16	0.07	0.049	0.24	0.12	0 089
VOC recovery credit = \$0.10/lb for air containing									
0.05 wt % VOC	12.2	4.19	3.12	15.9	6.56	4.45	23.3	11.8	8.48
0.50 wt % VOC	1.03	0.22	0.12	1.39	0.46	0.25	2.14	0.99	0.65
5.0 wt % VOC	(0.09)	(0.17)	(0.18)	(0.06)	(0.15)	(0.17)	(0.02)	(0.10)	(0.13)
VOC recovery credit = \$0.20/lb for air containing									
0.05 wt % VOC	12.0	3.97	2.90	15.6	6.34	4.23	23.1	11.62	8.27
0.50 wt % VOC	0.82	0.01	(0.10)	1.17	0.24	0.03	1.92	0.77	0.44
5.0 wt % VOC	(0.31)	(0.39)	(0.40)	(0.27)	(0.37)	(0.39)	(0.20)	(0.31)	(0.35)

Table V-4. Energy Effectiveness Summary

Absorber Conditions: VOC removal, 99%; $L_M/mG_M = 1.4$.
Stripper Conditions: Organic removal, 99%; steam ratio = 0.2 mole of steam/mole of air in.

	Energy Effectiveness (10^6 Btu/Mg of VOC) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
Operating Parameters	1.0	10	100	1.0	10	100	1.0	10	100
For air containing									
0.05 wt % VOC	622.1	623.3	615.8	773.0	771.9	763.9	1084.1	1086.4	1079.2
0.50 wt % VOC	62.2	62.3	61.6	77.3	77.2	76.4	108.4	108.6	107.9
5.0 wt % VOC	6.2	6.2	6.2	7.7	7.7	7.6	10.8	10.9	10.8

VI. SUMMARY AND CONCLUSIONS

Gas absorption as an emission control method is currently most widely used for the removal of water-soluble compounds from air streams, with water as the solvent or scrubbing fluid. When absorption is used for the control of VOC components that have low water solubility, other solvents (primarily organic liquids with very low vapor pressures) are used.

The suitability of gas absorption as a VOC emission control method compared to other alternatives (primarily thermal oxidation and carbon adsorption) is dependent on the availability of a suitable solvent, the concentration of VOC in the treated steam, and the value of the recovered VOC components.

Estimates of capital costs, operating costs, and cost effectiveness were developed for a number of combinations of conditions or variables to illustrate the effects of changes in these variables on costs. Some of the conclusions derived from the cost evaluations are as follows:

1. At low VOC concentrations the cost effectivenss of absorption is very sensitive to the vapor equilibrium properties of the VOC-solvent system used (expressed as m, the equilibrium curve slope)
2. Compared to other control methods, cost effectiveness of absorption is relatively insensitive to the degree of control attained within the ranges explored (90% to 99.9% VOC removal)
3. The incremental cost effectiveness of stripping absorber effluent water before it is discharged is very sensitive to the volume of gas treated and the concentration of VOC. From the standpoint of cost effectivensss alone the discharge of absorber effluent water without stripping may well appear to be preferable for control of emission sources containing low VOC concentrations; however, the effect on secondary emissions and water quality must also be considered.

APPENDIX A

ADDITIONAL CAPITAL AND COST SUMMARY CASES AND COST-EFFECTIVE TABLES

Table A-1. Capital Cost Summary for 99% VOC Removal and with Stripping

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.
Stripper Conditions: Steam ratio = 0.1 moles of steam/mole of air in.

	Capital Cost (10^3 \$) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74[a]		
	At Air Flow Rates (cfm X 10) of								
Equipment	1.0	10	100	1.0	10	100	1.0	10	100
Absorber system									
Tower and trays (packing)	33.6	133.8	741.1	42.2	165.6	870.9			
Blower	29.7	100.2	293.5	34.5	117.4	358.0			
Duct	8.0	16.0	27.5	8.0	16.0	27.5			
Pump	5.7	5.7	9.7	5.7	8.7	25.5			
Piping	1.0	1.0	3.4	1.0	3.4	9.7			
Instrumentation	14.8	14.8	14.8	14.8	14.8	14.8			
Stripping system									
Tower and trays (packing)	9.9	23.5	113.4	14.6	47.3	228.6			
Pump	5.7	5.7	9.7	5.7	8,7	25.5			
Piping	3.0	3.0	10.2	3.0	10.2	29.1			
Instruments	14.8	14.8	14.8	14.8	14.8	14.8			
Heat exchangers									
Feed-effluent	11.5	55.1	308.1	52.3	290.2	1752.9			
Steam preheater	1.5	5.7	25.0	5.0	21.3	103.7			
Stripper condenser	8.6	41.0	219.4	11.1	53.1	295.5			
Subtotal capital cost	147.8	420.3	1790.6	212.7	771.5	3756.5			
Total capital cost (+30%)	192.1	546.4	2327.8	276.5	1003.0	4883			

[a] Costs were not included for equilibrium curve slope of 5.74 because with that slope a steam ratio of 0.1 moles of steam/mole of air is insufficient for operation.

Table A-2. Capital Cost Summary for 99.9% Removal and No Stripping

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Capital Cost (10^3 \$) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
Equipment	1.0	10	100	1.0	10	100	1.0	10	100
Absorber system									
Tower and trays (packing)	44.1	172.9	901.2	56.6	219.9	1103.2	65.4	254.0	1253.9
Blower	35.6	121.5	373.6	42.4	146.5	468.3	47.3	164.8	537.9
Duct	8.0	16.0	27.5	8.0	16.0	27.5	8.0	16.0	27.5
Pump	5.7	5.7	9.7	5.7	8.8	25.5	6.0	12.8	45.6
Piping	1.0	1.0	3.4	1.0	3.4	9.7	1.6	4.5	17.4
Instrumentation	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Subtotal capital cost	109.2	331.9	1330.2	128.5	409.4	1649.0	143.1	466.9	1897.1
Total capital cost (+30%)	142.0	431.5	1729.3	167.1	532.2	2143.7	186.0	607.0	1466.2

Table A-3. Capital Cost Summary for 90% VOC Removal and No Stripping

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Capital Cost (10^3 \$) at Equilibrium Curve Slopes (m) of								
	0.28			2.20			5.74		
	At Air Flow Rates (cfm X 10^3) of								
Equipment	1.0	10	100	1.0	10	100	1.0	10	100
Absorber system									
Tower and trays (packing)	22.7	94.5	558.3	26.5	108.0	639.5	29.0	116.7	673.1
Blower	23.8	79.1	213.8	25.9	86.4	241.3	27.2	91.2	259.5
Duct	8.0	16.0	27.5	8.0	16.0	27.5	8.0	16.0	27.5
Pump	5.7	5.7	9.7	5.7	8.8	25.5	6.0	12.8	45.6
Piping	1.0	1.0	3.4	1.0	3.4	9.7	1.6	4.5	17.4
Instrumentation	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Subtotal capital cost	76.0	211.1	857.5	81.9	237.4	958.3	86.6	256.0	1037.9
Total capital cost (+30%)	98.8	274.4	1114.8	106.5	308.6	1245.8	112.6	332.8	1349.3

Table A-4. Capital Cost Summary for 99% VOC Removal and No Stripping

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Capital Cost (10^3 \$) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
	1.0	10	100	1.0	10	100	1.0	10	100
Absorber System									
Tower and trays (packing)	33.6	133.8	741.1	42.2	165.6	870.9	48.2	188.2	965.8
Blower	29.7	100.2	293.5	34.5	117.4	358.0	37.8	129.4	403.5
Duct	8.0	16.0	27.5	8.0	16.0	27.5	8.0	16.0	27.5
Pump	5.7	5.7	9.7	5.7	8.7	25.5	6.0	12.8	45.6
Piping	1.0	1.0	3.4	1.0	3.4	9.7	1.6	4.5	17.4
Instrumentation	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Subtotal capital cost	92.8	271.5	1090.0	106.2	325.9	1306.4	116.4	365.7	1474.6
Total capital cost (+30%)	120.6	353.0	1417.0	138.1	423.7	1698.3	151.3	475.4	1917.0

Table A-5. Annual Cost Summary for 99% VOC Removal and No Stripping

Absorber Conditions: 99% VOC Removal; $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Annual Cost (10^3 $) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
	1.0	10	100	1.0	10	100	1.0	10	100
Fixed costs (29% of capital)	35.0	102.4	410.9	40.0	122.9	492.5	43.9	137.9	555.9
Process water ($0.25/1000 gal)	0.3	2.9	28.8	2.1	20.7	207.2	5.9	58.9	588.7
Electricity ($0.03/kWh)	3.6	36.0	302.8	4.6	47.2	416.1	5.5	56.7	510.8
Steam ($2.50/1000 lb)									
Wastewater treat. ($0.25/1000 gal)	0.3	2.9	28.8	2.1	20.7	207.2	5.9	58.9	588.7
Cooling water ($0.10/1000 gal)									
Operating Labor ($15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost excluding BOD surcharge and recovery credit	52.3	157.3	784.4	61.9	224.6	1,336	74.3	325.5	2,257
BOD Surcharge									
0.05 wt % VOC in air	1.9	19.3	193	1.9	19.3	193	1.9	19.3	193
0.50 wt % VOC in air	19.3	193	1,930	19.3	193	1,930	19.3	193	1,930
5.0 wt % VOC in air	193	1930	19,300	193		19,300	193	1930	19,300
Net annual cost (credit)									
VOC recovery credit = 0 for air containing									
0.05 wt % VOC	54.2	176.6	977.4	63.8	243.9	1,529	76.2	344.8	2,450
0.5 wt % VOC	71.6	350.3	2,714.4	81.2	417.6	3,266	93.6	518.5	4,187
5.0 wt % VOC	245.3	2087.3	20,080	254.9	2154.6	20,640	267.3	2255.5	21,560

Table A-6. Annual Cost Summary for 99.9% VOC Removal and No Stripping

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Annual Cost (10^3 \$) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
Equipment	1.0	10	100	1.0	10	100	1.0	10	100
Fixed costs (29% of capital)	41.2	125.2	501.5	48.5	154.3	621.7	54.0	176.1	715.2
Process water (\$0.25/1000 gal)	0.3	2.9	28.8	2.1	20.7	207.2	5.9	58.9	588.7
Electricity (\$0.03/kWh)	4.9	49.3	435.8	6.6	67.0	613.9	8.0	81.9	762.3
Steam (\$2.50/1000 lb)									
Wastewater treat (\$0.25/1000 gal)	0.3	2.9	28.8	2.1	20.7	207.2	5.9	58.9	588.7
Cooling water (\$0.10/1000 gal)									
Operating labor (\$15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost exluding BOD surcharge and recovery credit	59.8	193.4	1,008.0	72.4	275.8	1,663.1	86.9	388.9	2,668
BOD surcharge									
0.05 wt % VOC in air	1.9	19.5	194.6	1.9	19.5	194.6	1.9	19.5	194.6
0.50 wt % VOC in air	19.5	194.6	1,946	19.5	194.6	1,946	19.5	194.6	1,946
5.0 wt % VOC in air	194.6	1946	19,460	194.6	1946	19,460	194.6	1946	19,460
Net annual cost (credit)									
VOC recovery, credit = 0 for air containing									
0.05 wt % VOC	61.7	212.9	1,202.6	74.3	295.3	1,857.7	88.8	408.4	2,862.9
0.5 wt % VOC	79.3	388.0	2,954	91.9	470.4	3,601.9	106.4	583.5	4,614.0
5.0 wt % VOC	254.4	2139.4	20,470	267.0	2221.8	21,120	281.5	2334.9	22,130

Table A-7. Annual Cost Summary for 90% VOC Removal and No Stripping

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Annual Cost (10^3 \$) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
	1.0	10	100	1.0	10	100	1.0	10	100
Fixed costs (29% of capital)	28.6	79.5	323.3	30.8	89.5	361.3	32.7	96.5	391.3
Process water (\$0.25/1000 gal)	0.3	2.9	28.8	2.1	20.7	207.2	5.9	58.9	588.7
Electricity (\$0.03/kWh)	2.4	24.1	184.3	2.8	28.7	230.5	3.1	32.9	272.7
Steam (\$2.50/1000 lb)									
Wastewater treat. (\$0.25/1000 gal)	0.3	2.9	28.8	2.1	20.7	207.2	5.9	58.9	588.7
Cooling water (\$0.10/1000 gal)									
Operating labor (\$15/hr)	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Total annual cost excluding BOD surcharge and recovery credit	44.7	122.5	578.3	50.9	172.7	1,019.1	60.7	260.3	1,854.5
BOD surcharge									
0.05 wt % VOC in air	1.8	17.5	175.3	1.8	17.5	175.3	1.8	17.5	175.3
0.50 wt % VOC in air	17.5	175.3	1,753	17.5	175.3	1,753	17.5	175.3	1,753
5.0 wt % VOC in air	175.3	1753	17,530	175.3	1753	17,530	175.3	1753	17,530
Net annual cost (credit)									
VOC recovery credit = 0 for air containing									
0.05 wt % VOC	46.5	140.0	753.4	52.7	190.2	11,944	62.5	277.8	2,029.8
0.5 wt % VOC	62.2	297.8	2,331.1	68.4	348.0	2,772.1	78.2	435.6	3,607.5
5.0 wt % VOC	220.0	1875.5	18,110	226.2	1925.7	18,550	236.0	2013.3	19,380

Table A-8. Annual Cost Summary for 99% VOC Removal, with Stripping and Steam Ratio of 0.1

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.
Stripper Conditions: Steam ratio = 0.1 mole of steam/mole of air in.

	Annual Cost (10^3 $) at Equilibrium Curve Slopes (m) of					
	0.28			2.02		
	At Air Flow Rates (cfm X 10^3) of					
	1.0	10	100	1.0	10	100
Fixed costs (29% of capital)	55.7	158.5	675.1	80.2	290.9	1416.1
Process water ($0.25/m gal)	0.3	2.9	28.8	2.1	20.7	207.0
Electricity ($0.03/kWh)	3.8	36.2	304.0	4.8	48.0	424.5
Steam ($2.50/1000 lb)	6.5	64.5	645.2	9.3	93.3	932.9
Wastewater treat ($0.25/1000 gal)	0.4	3.6	36.0	2.1	21.4	214.4
Cooling water ($0.10/1000 gal)	0.7	7.3	72.6	0.7	7.3	72.6
Operating labor ($15/hr)	32.9	32.9	32.9	32.9	32.9	32.9
Total annual cost excluding BOD Surcharge and recovery credit	100.3	305.9	1794.6	132.1	514.5	3300.4
BOD surcharge						
0.05 wt % VOC in air	0.02	0.2	1.9	0.02	0.2	1.9
0.50 wt % VOC in air	0.2	1.9	19.3	0.2	1.9	19.3
5.0 wt % VOC in air	1.9	19.3	193.0	1.9	19.3	193.0
Net annual cost (credit)						
VOC recovery credit - 0						
0.05 wt % VOC	100.3	306.1	1796.5	132.1	514.7	3302.3
0.5 wt % VOC	100.5	307.8	1813.9	132.3	516.4	3319.7
5.0 wt % VOC	102.2	325.2	1987.6	134.0	533.8	3394.3
VOC recovery credit - $0.10/lb						
0.05 wt % VOC	98.4	287.0	1606	130.2	495.6	3110
0.50 wt % VOC	81.4	116.9	(95.1)	113.2	325.5	1411
5.0 wt % VOC	(88.7)	(1584)	(17,100)	(56.9)	(1375)	(15,700)
VOC recovery credit - $0.20/lb						
0.05 wt % VOC	96.5	267.9	1415	128.3	476.5	2920
0.50 wt % VOC	62.3	(73.9)	(2003)	94.1	134.7	(498)
5.0 wt % VOC	(279.6)	(3492)	(36,180)	(247.2)	(3284)	(34,790)

Table A-9. Annual Cost Summary for 99% VOC Removal, with Stripping, and Steam Ratio of 0.2

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.
Stripper Conditions: Steam ratio = 0.2 mole of steam/mole of air in.

	Annual Cost (10^3 $) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
Equipment	1.0	10	100	1.0	10	100	1.0	10	100
Fixed costs (29% of capital)	57.3	169.8	725.7	81.7	300.7	1,510	127.8	567.0	3088
Process water ($0.25/m gal)	0.3	2.9	28.8	2.1	20.7	207.2	5.9	58.9	589
Electricity ($0.03/kWh)	3.8	36.2	304.0	4.8	48.0	424.5	5.7	59.1	534.5
Steam ($2.50/1000 lb)	12.5	125.0	1,250	15.4	153.7	1,537	21.9	219.0	2,190
Wastewater treat ($0.25/1000 gal)	0.4	4.3	433.0	2.2	22.2	221.7	6.0	60.3	603
Cooling water ($0.10/1000 gal)	1.5	14.5	145.1	1.5	14.5	145.1	5.8	58.0	580
Operating labor ($15/hr)	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9
Total annual cost excluding BOD surcharge and recovery credit	108.7	385.6	2,919.5	140.6	592.7	4,078	206.0	1,055	7,615.4
BOD surcharge									
0.05 wt % VOC in air	0.02	0.2	1.9	0.02	0.2	1.9	0.02	0.2	1.9
0.50 wt % VOC in air	0.2	1.9	19.3	0.2	1.9	19.3	0.2	1.9	19.3
5.0 wt % VOC in air	1.9	19.3	193	1.9	19.3	193	1.9	19.3	193
Net annual cost (credit)									
VOC recovery credit 0									
0.05 wt % VOC	108.7	385.8	2,921.4	140.6	592.9	4,079.9	206.0	1055.2	7,617
0.5 wt % VOC	108.9	387.5	2,938.8	140.8	594.6	4,097.3	206.2	1056.9	7,635
5.0 wt % VOC	110.6	404.9	3,112.5	142.5	612.0	4,271	207.9	1074.3	7,808
VOC recovery credit $0.10/lb									
0.05 wt % VOC	106.8	366.7	2,730.5	138.7	573.8	3,889	204.1	1036.1	7,416
0.50 wt % VOC	89.8	196.6	1,030	121.7	403.7	2,188.3	187.1	866.0	5,726
5.0 wt % VOC	(80.3)	(1504.1)	(15,980)	(48.4)	(1297.0)	(14,820)	(17.0)	(834.7)	(11,280)
VOC recovery credit $0.20/lb									
0.05 wt % VOC	104.9	347.6	2,539	136.8	554.7	3,698.2	202.2	1017.0	7,235
0.50 wt % VOC	70.7	5.8	(878.2)	102.6	212.9	280.3	168.0	675.2	3,818
5.0 wt % VOC	(271.7)	(3412)	(35,060)	(239.2)	(3205)	(33,900)	(173.8)	(2742)	(30,360)

Table A-10. Cost Effectiveness Summary for 99% VOC Removal for Tray Column with Water Discharged without Stripping and No VOC Recovered

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Cost Effectiveness (10^3 \$/Mg of VOC) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
	1.0	10	100	1.0	10	100	1.0	10	100
VOC Recovery Credit = 0									
0.05 wt % VOC	6.19	2.02	1.12	7.29	2.79	1.75	8.71	3.94	2.80
0.50 wt % VOC	0.82	0.40	0.31	0.93	0.48	0.37	1.07	0.59	0.48
5.0 wt % VOC	0.28	0.24	0.23	0.29	0.25	0.24	0.31	0.26	0.25

Table A-11. Cost Effectiveness Summary for 99.9% VOC Removal for Tray Column, with Water Discharged without Stripping and No VOC Recovered

Absorber Conditions: $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Cost Effectiveness (10^3 \$/Mg of VOC) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm X 10^3) of								
	1.0	10	100	1.0	10	100	1.0	10	100
VOC Recovery Credit = 0									
0.05 wt % VOC	6.99	2.41	1.36	8.42	3.35	2.10	10.1	4.63	3.24
0.50 wt % VOC	0.90	0.44	0.33	1.04	0.53	0.41	1.21	0.66	0.52
5.0 wt % VOC	0.29	0.24	0.23	0.30	0.25	0.24	0.32	0.26	0.25

Table A-12. Cost Effectiveness Summary for 90% VOC Removal for Absorber, with Water Discharged without Stripping and No VOC Recovered

Absorber Conditions: VOC removal, 90% ; $L_M/mG_M = 1.4$; VOC in air = 0.05, 0.5, 5.0 wt %.

	Cost (10^3 \$) at Equilibrium Curve Slopes (m) of								
	0.28			2.02			5.74		
	At Air Flow Rates (cfm x 10^3) of								
	1.0	10	100	1.0	10	100	1.0	10	100
VOC Recovery Credit = 0									
0.05 wt % VOC	5.85	1.76	0.95	6.63	2.39	1.50	7.86	3.49	2.55
0.50 wt % VOC	0.78	0.37	0.29	0.86	0.44	0.35	0.98	0.55	0.45
5.0 wt % VOC	0.28	0.24	0.23	0.28	0.24	0.23	0.30	0.25	0.24

Table A-13. Cost Effectiveness Summary for 99% VOC Removal and Steam Ratio of 0.1

Absorber Conditions: VOC removal, 99%; L_M/mG_M = 1.4%; VOC in air - 0.05, 0.5, 5.0 wt %.
Stripper Conditions: Organic removal, 99%; steam ratio = 0.1 mole of steam/mole of air in.

	Cost Effectiveness (10^3 \$/Mg of VOC) at Equilibrium Curve Slopes (m) of					
	0.28			2.02		
	At Air Flow Rates (cfm X 10^3) of					
	1.0	10	100	1.0	10	100
VOC Recovery Credit = 0						
0.05 wt % VOC	11.5	3.50	2.05	15.1	5.88	3.78
0.50 wt % VOC	1.15	0.35	0.21	1.51	0.59	0.38
5.0 wt % VOC	0.12	0.037	0.023	0.15	0.061	0.039
VOC Recovery Credit = \$0.10/lb						
0.05 wt % VOC	11.3	3.28	1.84	14.9	5.67	3.56
0.50 wt % VOC	0.93	0.13	(0.01)	1.29	0.37	0.16
5.0 wt % VOC	(0.10)	(0.18)	(0.20)	(0.07)	(0.16)	(0.18)
VOC Recovery Credit = \$0.20/lb						
0.05 wt % VOC	11.0	3.06	1.62	14.7	5.45	3.34
0.50 wt % VOC	0.11	(0.08)	(0.23)	1.08	0.15	(0.06)
5.0 wt % VOC	(0.32)	(0.40)	(0.41)	(0.28)	(0.38)	(0.40)

APPENDIX B

SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

I. Capital Cost Parameters

Basis

10,000 SCFM of air at 25°C containing 0.5 wt % acetone.

VOC (acetone) removal efficiency of absorber, 99.0%.

Solvent: water at 25°C, single-pass usage.

A. Tray-Column Parameters

1. Liquid Rate

For a dilute solution (ref 1):

$$m = \frac{\gamma_1 P_1}{P_T} = \frac{(6.7)\ (229\ \text{mm})}{760\ \text{mm}} = 2.02,$$

where

m = equilibrium curve slope,

γ = activity coefficient of acetone at 25°C,

P_1 = pure component vapor pressure, mm Hg, at 25°C,

P_T = total pressure, mm Hg;

if we let

$$\frac{L_M}{mG_M} = 1.4,$$

where

$$\frac{L_M}{G_M} = \text{liquid-to-gas mole ratio},$$

$$G_M = \frac{PV}{RT} = \frac{(14.7)\ (10{,}000)\ (60)}{(10.71)\ (460 + 77)} = \frac{1534\ \text{lb-moles of air}}{\text{hr}};$$

then

$$L_M = 1.4\ mG_M = (1.4)\ (2.02)\ (1534) = \frac{4340\ \text{lb-moles of water}}{\text{hr}}$$

or

$$\frac{(4340)\ (18)}{(8.33)\ (60)} = 156 \text{ gpm of water.}$$

2. Number of Theoretical Trays, N_p

Using Fig. B-I to estimate the number of theoretical trays required, at a VOC removal efficiency of 99%, $Y_1/Y_2 = 100$ and $mG_M/L_M = 0.71$. From Fig. B-1, $N_p = 10.0$, where y_1 = mole fraction of VOC in scrubber inlet gas, y_2 = mole fraction of VOC in scrubber outlet gas, and N_p = number of theorectical plates required.

3. Tray Efficiency

The tray efficiency can be expressed as[2]

$$E_o = \frac{0.377}{\left(mM_L\mu_L/\rho_L\right)^{0.209}} = \frac{0.377}{[(2.02)\ (18)\ (1.0)/62.4]^{0.209}} = 0.422,$$

where

E_o = tray efficiency,
m = equilibrium curve slope,
M_L = molecular weight of liquid,
μ_L = viscosity of liquid, centipoise,
ρ_L = density of liquid, lb/ft^3.

4. Actual Number of Trays, N

$$N = \frac{N_p}{E_o} = \frac{10.0}{0.422} = 23.7 \text{ or } 24 \text{ trays.}$$

5. Tower Diameter

The superficial gas velocity in a bubble-cap tray tower at flooding is estimated by[3]

$$V_F = C_F \left(\frac{\rho_L - \rho_G}{\rho_G}\right)^{0.5},$$

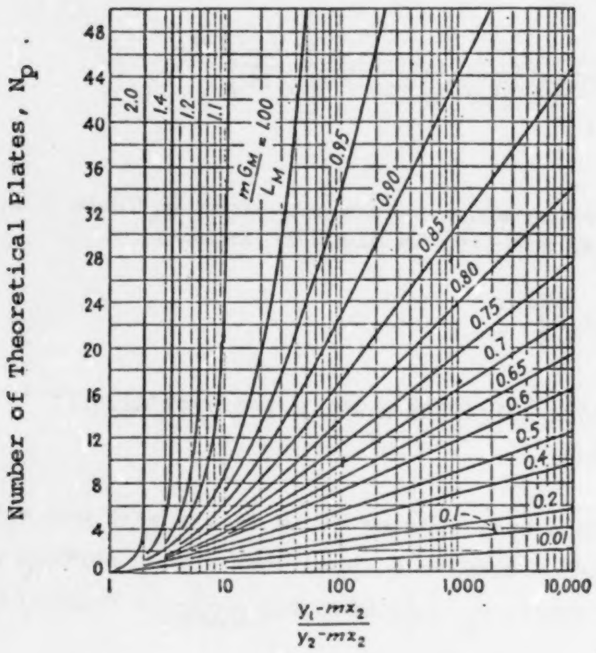

Fig. B-1. Number of Theoretical Plates in an Absorption Column for Constant mG_M/L_M.

where

V_F = superficial flooding velocity, fps,
ρ_L = liquid density, lb/ft^3,
ρ_G = gas density, lb/ft^3,
C_F = a constant determined by the following equation

$$C_F = \left[a \log \frac{1}{(L'/G')\left(\rho_G/\rho_L\right)^{0.5} + b}\right] \left(\frac{\sigma}{20}\right)^{0.2},$$

where

a and b = constants whose values are given in Table B 1, in which t, the tray spacing, is given in inches,

$$(L'/G') \text{ X } \left[\left(\rho_G/\rho_L\right)\right]^{0.5}$$

$$= (4340 \text{ X } 18)/(1534 \text{ X } 29) \text{ X } [(0.0749/62.4)]^{0.5}$$
$$= 0.0608.$$

From Table B-1, with a tray spacing of 18 in., a = (0.041 X 18) + 0.0135 = 0.0873, and b = (0.0047 X 18) + 0.068 = 0.1526; then with a surface tension of 72.0 dynes/cm (water at 25OC), $C_F = \left(0.0873 \log \frac{1}{0.0608} + 0.1526\right) \left(\frac{72.0}{20}\right)^{0.2} = 0.334$, and

$$V_F = 0.334 \left(\frac{62.4 - 0.0749}{0.0749}\right)^{0.5} = 9.63 \text{ fps.}$$

Assuming the actual superficial vapor velocity to be a conservative 50% of flooding velocity, V = (0.5) (9.63) = 4.82 fps, the tower cross-sectional area = 10,000 cfm X (min/60 sec) X min X (sec/4.82 ft) = 34.5 ft^2, and the diameter = $[(4 \text{ X } 34.5)/\Pi]^{0.5}$ = 6.63 ft.

6. **Tower Height**

With 18-in. tray spacing the overall height = [18 X (ft/12 in.) X no. of trays + (2 X diam) = 18 X 24)/(12) + (2 X 6.6) = 49.2 ft.

7. **Tower Pressure Drop**

With a Δp of 3 in. H_2O per tray the total tower pressure drop = (3 X 24) = 72.0 in. H_2O.

Table B-1. Flooding Constants, C_f[a]

Range of $\frac{L'}{G'}\left(\frac{\rho_G}{\rho_L}\right)^{0.5}$	a	b
0.01-0.03 use values at 0.03		
0.03-0.2	0.0041t + 0.0135	0.0047t + 0.068
0.2-1.0	0.0068t + 0.049	0.0028t + 0.044
	Perforated Trays	
Flooding constant C_f		
Range of $\frac{L'}{G'}\left(\frac{\rho_G}{\rho_L}\right)^{0.5}$		
0.01-0.1 use values at 0.1		
0.1-1.0	0.0062t + 0.0385	0.00253t + 0.05

[a] From ref 3.

B. Packed-Column Parameters

Basis: 1-in. porcelain Raschig rings; other criteria the same as those for the tray column.

1. Tower Diameter

Using the correlation shown in Fig. B-2, we calculated the factor (L'/V') X $\left(\rho_G/\rho_L\right)^{0.5}$, where L' = liquid flow rate, lb/hr, V' = gas flow rate, lb/hr, ρ_G = gas density, lb/ft^3, and ρ_L = liquid density, lb/ft^3, to be:

$$\frac{(4340)\ (18)}{(1534)\ (29)} \left(\frac{0.0749}{62.4}\right)^{0.5} = 0.0608.$$

Then, from Fig. B-2,

$$\frac{\left[\left(G'^{\,2}\right)\right]\ \left(\frac{\alpha}{\varepsilon^3}\right)\ \left(\mu'_2\right)^{0.2}}{\left(g_c\right)\ \left(\rho_G\right)\left(\rho_L\right)} = 0.13,$$

where

G = gas flow rate at flooding conditions, lb/sec-ft^2 tower cross-section,
Δ/ε^3 = packing factor from Fig. B-3 = 170,
ρ_G = gas density, lb/ft^3,
ρ_L = liquid density, lb/ft^3,
μ'_2 = liquid viscosity, centipoises,
g_c = gravitation constant, 32.2 ft/sec^2:

$$G' = \left[\frac{(0.13)\ (32.2)\ (0.0749)\ (62.4)}{(170)\ (1.0)^{0.2}}\right]^{0.5} = 0.339\ \text{lb/sec-ft}^2.$$

Designed for 60% of flooding velocity the design rate, $G_{f'}$ = (0.6) (0.339) = 0.204 lb/sec-ft^2.

The tower cross-sectional area is

$$\frac{1534\ \text{lb-moles}}{\text{hr}} \text{ X } \frac{29\ \text{lb}}{\text{lb-moles}} \text{ X } \frac{\text{sec-ft}^2}{0.204\ \text{lb}} \text{ X } \frac{\text{hr}}{3600\ \text{sec}} = 60.6\ \text{ft}^2.$$

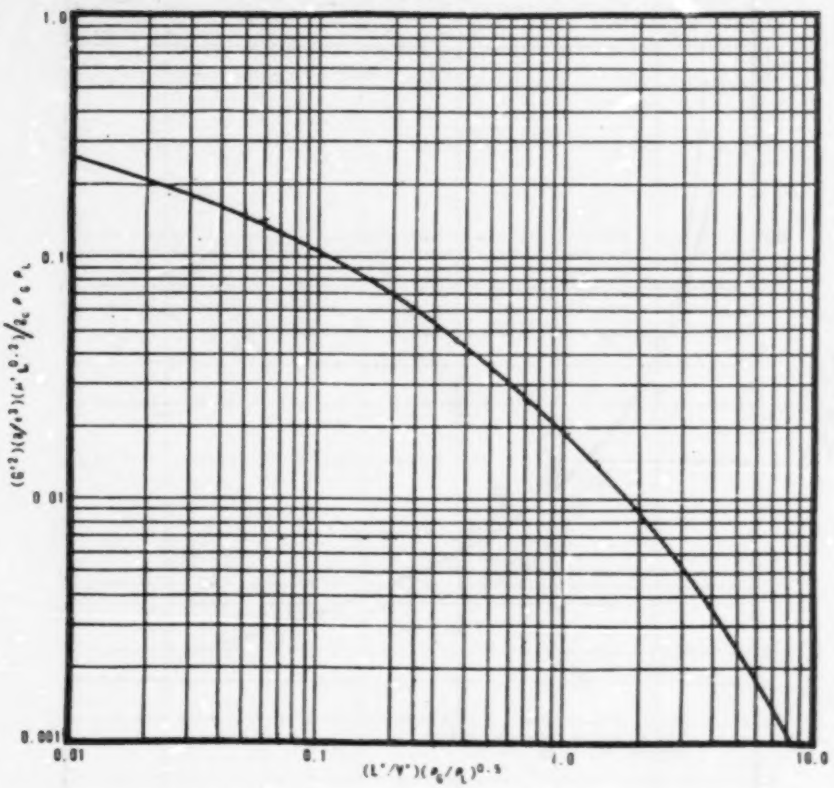

Fig. B-2. Correlation for Flooding Rate in Randomly Packed Towers (from ref 4)

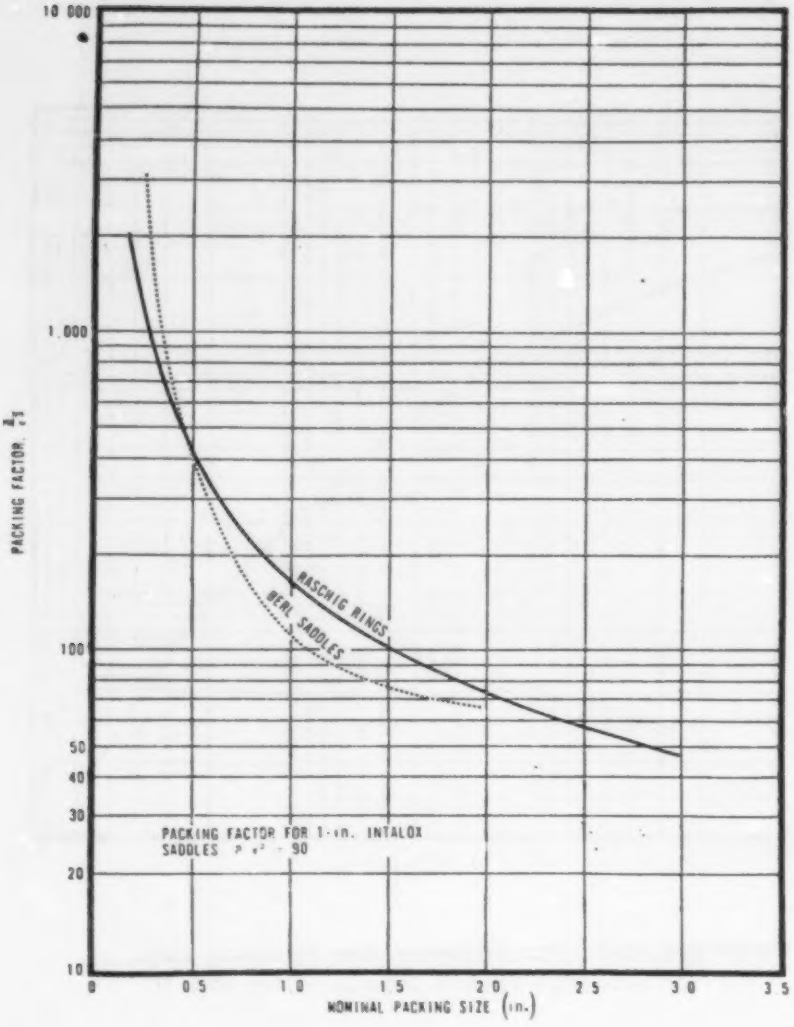

Fig. B-3. Packing Factors for Raschig Rings and Saddles

The tower diameter was then calculated as

$$D = \left[\frac{(60.6)\ (4)}{\pi}\right]^{0.5} = 8.8 \text{ ft.}$$

2. **Number of Transfer Units, N_{OG}**

Using Fig. B-4 to estimate the number of transfer units required, at a VOC removal efficiency of 99.0%, $Y_1/Y_2 = 100$, and $mG_M/L_M = 0.71$: $N_{OG} = 11.8$.

3. **Height of a Transfer Unit**

The height of a transfer unit, H_{OG}, is obtained by the following relationships between H_G (the height, in feet, of a gas-transfer unit) and H_L (the height, in feet, of a liquid-transfer unit):

$$H_{OG} = H_G + m\left(\frac{G_M}{L_M}\right)H_L \quad ,$$

where

$$H_G = \frac{\alpha G^{\beta}}{L_{\gamma}}\left(\frac{\mu G}{\rho_G \rho_G}\right)$$

and

$$H_L = \phi\left(\frac{L}{\mu_L}\right)^{n}\left(\frac{\mu_L}{\rho_L D_L}\right)^{0.5},$$

in which

m = equilibrium curve slope,
G = superficial gas rate, lb/hr-ft^2,
L = superficial liquid rate, lb/hr-ft^2,
α = a packing constant from Table B-2,
β = a packing constant from Table B-2,
γ = a packing constant from Table B-2,
μ_G = a gas viscosity, lb/hr-ft^2
ρ_G = gas density, lb/ft^2,
D_G = gas diffusivity, ft^2/hr

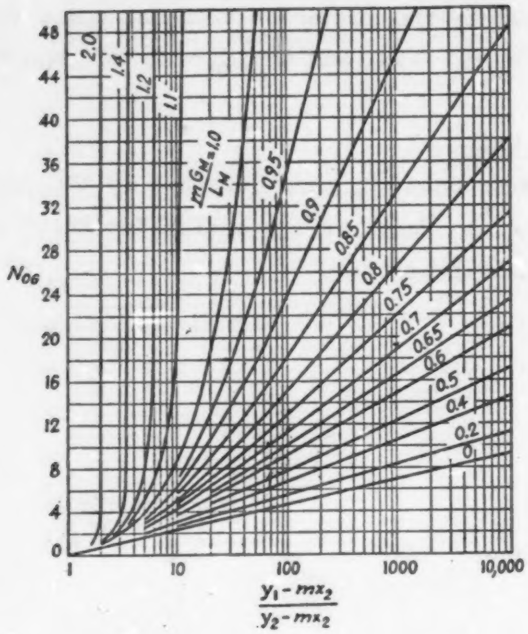

Fig. B-4. Number of Transfer Units in an Absorption Column for Constant mG_M/L_M

Table B-2. Constants for Use in Determining Gas Film's Height of Transfer Units[a]

Packing	Packing Constants			Mass Flow Rates [lb/(hr)(ft^2)]	
	α	β	γ	Gas	Liquid
Raschig rings					
3/8 in.	2.32	0.45	0.47	200 to 500	500 to 1,500
1 in.	7.00	0.39	0.58	200 to 800	400 to 500
	6.41	0.32	0.51	200 to 600	500 to 4,500
1-1/2 in.	17.30	0.38	0.66	200 to 700	500 to 1,500
	2.58	0.38	0.40	200 to 700	1,500 to 4,500
2 in.	3.82	0.41	0.45	200 to 800	500 to 4,500
Berl saddles					
1/2 in.	32.40	0.30	0.74	200 to 700	500 to 1,500
	0.81	0.30	0.24	200 to 700	1,500 to 4,500
1 in.	1.97	0.36	0.40	200 to 800	400 to 4,500
1-1/2 in.	5.05	0.32	0.45	200 to 1,000	400 to 4,500
3-in. partition rings	650	0.58	1.06	150 to 900	3,000 to 10,000
Spiral rings (stacked staggered)					
3 in. single spiral	2.38	0.35	0.29	130 to 700	3,000 to 10,000
3 in. triple spiral	15.60	0.38	0.60	200 to 1,000	500 to 3,000
Drip-point grids					
No. 6146	3.91	0.37	0.39	130 to 1,000	3,000 to 6,500
No. 6295	4.56	0.17	0.27	100 to 1,000	2,000 to 11,500

[a] Adapted from ref 4.

(values for the group known as the Schmidt number are given in Table B-3)

μ_L = liquid viscosity, lb/hr-ft,

ϕ = a packing constant from Table B-4,

η = a packing constant from Table B-4,

ρ_L = liquid density, lb/ft^3,

D_L = liquid diffusivity, ft^2/hr

(the values for the group $\mu/\rho_L D_L$, the Schmidt number, are given in Table B-5).

The values for the group $\mu_G/\rho_G D_G$, also known as the Schmidt number, are given in Table B-3; the values for the group $\mu/\rho_L D_L$ are given in Table B-5; and the values for G and L are, respectively,

$$\frac{1534\ \text{lb-moles}}{\text{hr}} \times \frac{29\ \text{lb}}{\text{lb-mole}} \times \frac{1}{60.6\ \text{ft}^2} = 734.1$$

and

$$\frac{4340\ \text{lb-moles}}{\text{hr}} \times \frac{18\ \text{lb}}{\text{lb-mole}} \times \frac{1}{60.6\ \text{ft}^2} = 1289.1.$$

Then

$$H_G = \frac{(7.0)\ (734.1)^{0.39}}{(1289.1)^{0.58}}\ (1.60)^{0.5} = 1.82\ \text{ft},$$

and

$$H_L = \phi \left(\frac{L}{\mu_L}\right)^{\eta} \left(\frac{\mu_L}{\rho_L D_L}\right)^{0.5},$$

$$H_L = (0.01) \left(\frac{1289.1}{(2.42)\ (0.894)}\right)^{0.22} (767)^{0.5} = 1.13\ \text{ft},$$

$$H_{OG} = H_G + m\left(\frac{G_m}{L_m}\right) H_L\ ,$$

$$H_{OG} = 1.82 + 2.02 \left(\frac{1534}{4340}\right) (1.13) = 2.63\ \text{ft}.$$

Table B-3. Diffusion Coefficients of Gases and Vapors in Air at 25°C and 1 atm[a]

Substance	Diffusivity (cm^2/sec)	Schmidt No., $\frac{\mu}{\rho D}$
Ammonia	0.236	0.66
Carbon dioxide	0.164	0.94
Hydrogen	0.410	0.22
Oxygen	0.206	0.75
Water	0.256	0.60
Carbon disulfide	0.107	1.45
Ethyl ether	0.093	1.66
Methanol	0.159	0.97
Ethyl alcohol	0.119	1.30
Propyl alcohol	0.100	1.55
Butyl alcohol	0.090	1.72
Amyl alcohol	0.070	2.21
Hexyl alcohol	0.059	2.60
Formic acid	0.159	0.97
Acetic acid	0.133	1.16
Propionic acid	0.099	1.56
i-Butyric acid	0.081	1.91
Valeric acid	0.067	2.31
i-Caproic acid	0.060	2.58
Diethyl amine	0.105	1.47
Butyl amine	0.101	1.53
Aniline	0.072	2.14
Chlorobenzene	0.073	2.12
Chlorotoluene	0.065	2.38
Propyl bromide	0.105	1.47
Propyl iodide	0.096	1.61
Benzene	0.888	1.76
Toluene	0.084	1.84
Xylene	0.071	2.18

Table B-3 (Cont'd)

Substance	Diffusivity (cm /sec)	Schmidt No., $\frac{\mu}{D}$
Ethyl benzene	0.077	2.01
Propyl benzene	0.059	2.62
Diphenyl	0.068	2.28
_n_-Octane	0.060	2.58
Mesitylene	0.067	2.31
Acetone[b]		1.60 32°F

[a] Adapted from ref 4.

Table B-4. Constants for Use in Determining Liquid Film's Height of Transfer Units[a]

Packing	ϕ	η	Liquid Mass Flow Rate [lb/(hr)(ft^2)]
Raschig rings			
3/8 in.	0.00182	0.46	400 to 15,000
1/2 in.	0.00357	0.35	400 to 15,000
1 in.	0.0100	0.22	400 to 15,000
1-1/2 in.	0.0111	0.22	400 to 15,000
2 in.	0.0125	0.22	400 to 15,000
Berl saddles			
1/2 in.	0.00666	0.28	400 to 15,000
1 in.	0.00588	0.28	400 to 15,000
1-1/2 in.	0.00625	0.28	400 to 15,000
3-in. partition rings	0.0625	0.09	3,000 to 14,000
Spiral rings (stacked staggered)			
3 in. single spiral	0.00909	0.28	400 to 15,000
3 in. triple spiral	0.0116	0.28	3,000 to 14,000
Drip-point grids			
No. 6146	0.0154	0.23	3,500 to 30,000
No. 6295	0.00725	0.31	2,500 to 22,000

[a] Adapted from ref 4.

Table B-5. Diffusion Coefficients in Liquids at 20°C[a]

Solute[b]	$D \times 10^5$ $(cm^2/sec) \times 10^5$	$\frac{\mu}{\rho D}$
O_2	1.80	558
CO_2	1.77	559
N_2O	1.51	665
NH_3	1.76	570
CI_2	1.22	824
Br_2	1.20	840
H_2	5.13	196
N_2	1.64	613
HCl	2.64	381
H_2S	1.41	712
H_2SO_4	1.73	580
HNO_3	2.60	390
Acetone	-	767[c]
Acetylene	1.56	645
Acetic acid	0.88	1,140
Methanol	1.28	785
Ethanol	1.00	1,005
Propanol	0.87	1,150
Butanol	0.77	1,310
Allyl alcohol	0.93	1,080
Phenol	0.84	1,200
Glycerol	0.72	1,400
Pyrogallol	0.70	1,440
Hydroquinone	0.77	1,300
Urea	1.06	946
Resorcinol	0.80	1,260
Urethane	0.92	1,090
Lactose	0.43	2,340
Maltose	0.43	2,340
Glucose	0.60	-

Table B-5. (Cont'd)

Solute[b]	D X 10^5 (cm^2/sec) X 10^5	$\frac{\mu}{\rho D}$
Mannitol	0.58	1,730
Raffinose	0.37	2,720
Sucrose	0.45	2,230
Sodium chloride	1.35	745
Sodium hydroxide	1.51	665
CO[d]	3.40	445
Phenol[d]	0.80	1,900
Chloroform[d]	1.23	1,230
Phenol[e]	1.54	479
Chloroform[e]	2.11	350
Acetic acid[e]	1.92	384
Ethylene dichloride[d]	2.45	301

[a] Adapted from ref 4.

[b] Solvent is water except where indicated.

[c] Value calculated by method in ref 5.

[d] Solvent is ethanol.

[e] Solvent is benzene.

4. **Tower Height[4]**

The packed height, Z, = N_{OG} X H_{OG} = (11.8) (2.63) = 31.0 ft. The total tower height, Z + (2. X diam), = 31.0 + (2) (8.8) = 48.6 ft.

5. **Tower Pressure Drop, ΔP (ref 4.)**

$$\frac{\Delta P}{Z} = m_1 \left(10^{-8}\right)\left(10^{\eta L'/\rho L}\right) \frac{G'}{\rho_G} ,$$

where

ΔP = pressure drop, lb/ft,
Z = packed height of tower, ft,
m_1 = pressure drop constant (Table B-6),
η = pressure drop constant (Table B-6),
L' = superficial mass-liquid velocity, lb/hr-ft^2,
G' = superifical mass-gas velocity, lb/hr-ft^2,
ρ_L = liquid density, lb/ft^3,
ρ_G = gas density lb/ft^3.

Then

$$\Delta P = (32.1) \left(10^{-8}\right) \left[10^{(0.00434)(1289.1)(62.4)}\right] \frac{(734.1)^2}{0.0749} (31.0) ,$$

or

$$\Delta P = 88.0 \text{ lb/ft}^2$$

$$\frac{88.0}{5.197} = 16.9 \text{ in. } H_2O.$$

II. **Stripping Tower Parameters**

Basis

Absorber—10,000 scfm of air at 25°C containing 0.5 wt % acetone; VOC (acetone) removal efficiency, 99.0%; solvent, water; single-pass usage, $mG_M/L_M = 0.7$

Stripper—VOC (acetone) removal efficiency from water, 99.0%; heat supplied by direct injection of steam (no reboiler); steam usage, 0.1 mole of steam/mole of air treated in absorber.

Table B-6. Pressure-Drop Constants for Tower Packing[a]

Packing	Nominal Size (in.)	m	n	Liquid Mass Flow Rate [(lb/(hr)(ft^2)]	Range of P/Z [lb/(ft^2)(ft)]
Raschig rings	1/2	139	0.00720	300 to 8,600	0 to 2.6
	3/4	32.90	0.00450	1,800 to 10,800	0 to 2.6
	1	32.10	0.00434	360 to 27,000	0 to 2.6
	1-1/2	12.08	0.00398	720 to 18,000	0 to 2.6
	2	11.13	0.00295	720 to 21,000	0 to 2.6
Berl saddles	1/2	60.40	0.00340	300 to 14,100	0 to 2.6
	3/4	24.10	0.00295	360 to 14,400	0 to 2.6
	1	16.01	0.00295	720 to 78,800	0 to 2.6
	1-1/2	8.01	0.00225	720 to 21,600	0 to 2.6
Intalox saddles	1	12.44	0.00277	2,520 to 14,000	0 to 2.6
	1-1/2	5.66	0.00225	2,520 to 14,400	0 to 2.6
Drip-point grid tiles	No. 6146 continuous flue	1.045	0.00214	3,000 to 17,000	0 to 0.5
	Cross flue	1.218	0.00227	300 to 17,500	0 to 0.5
	No. 6295 continuous flue	1.088	0.00224	850 to 13,500	0 to 0.5
	Cross flue	1.435	0.00167	900 to 12,500	0 to 0.5

[a] Adapted from ref 4.

A. Tray Column Parameters

1. Number of Theoretical Trays (N_p)

Estimating N_p by the equation*[5]

$$N_p = \frac{\ln \left[1 - \left(\frac{L_m}{mG_m}\right)\left(\frac{x_1 - my_2}{x_2 - my_2}\right) + \frac{L_M}{mG_M}\right]}{\ln \left(\frac{mG_M}{L_M}\right)} .$$

where

N_p = number of theoretical plates,
m = slope of equilibrium curve at liquid-discharge conditions,
L_M = liquid rate, mole/hr,
G_M = vapor rate, mole/hr,
x_1 = mole fraction of VOC in liquid in,
x_2 = mole fraction of VOC in liquid out,
y_2 = mole fraction of VOC in vapor in.

With sparged steam as the inlet vapor Y^2 is 0 and at a removal efficiency of 99.0%, x_1/x_2 is 100.

For a dilute aqueous solution of acetone at 212°F, the value of m at the origin is 36.9 (ref 5). Then

L_M = 4340 lb-moles/hr of water (from absorber calculation),

$$G_M = \left(1534 \frac{\text{lb-moles of air}}{\text{hr}}\right) \left(0.1 \frac{\text{lb-mole of steam}}{\text{lb-mole of air}}\right) = 153.4 \text{ lb-moles steam/hr,}$$

---

*This equation assumes straight-line equilibrium and operating lines, conditions that are generally approached closely only with very dilute solutions. The equation can generally be used only for determining the number of plates in the stripping section in actual design calculations. (Other calculations are used for determining the number of plates in the enriching section.) However, as most of the trays are usually required in the stripping section, the equation can be used for rough estimates of the total number of trays, which are of sufficient accuracy for the purposes of this report.

and

$$N_p = \frac{\ln\left[\left(1 - \frac{(4340)}{(36.9)\ (153.4)}\right)\left(\frac{100}{1}\right) + \left(\frac{(4340)}{(36.9)\ (153.4)}\right)\right]}{\ln \frac{(36.9)\ (153.4)}{(4340)}} = 11.9.$$

2. Number of Actual Trays

From Fig. 15-10 of ref 2, in which $\mu_F = 0.28$ cp and $\gamma = y/x$ is conservatively assumed to be 36.9, $E_O = 0.27$, where E_O = tray efficiency and γ = relative volatiles of key components:

$$N = \frac{N_p}{E_O} = \frac{11.9}{0.27} = 44 \text{ trays.}$$

3. Tower Diameter

The equation[6]

$$V = K\left(\frac{\rho_L - \rho_G}{\rho_G}\right)^{0.5} ,$$

where

V = superficial vapor velocity, fps,

ρ_L = liquid density, lb/ft^3,

ρ_G = vapor density, lb/ft^3,

K = empirical constant determined from Fig. B-5,

is used to determine the superficial gas velocity that will prevent excessive entrainment.

From Fig. B-5, using 18-in. tray spacing and a liquid seal depth of 1 in., $K = 0.14$ and

$$V = 0.14\left(\frac{59.8 - 0.0373}{0.0373}\right)^{0.5} = 5.6 \text{ fps.}$$

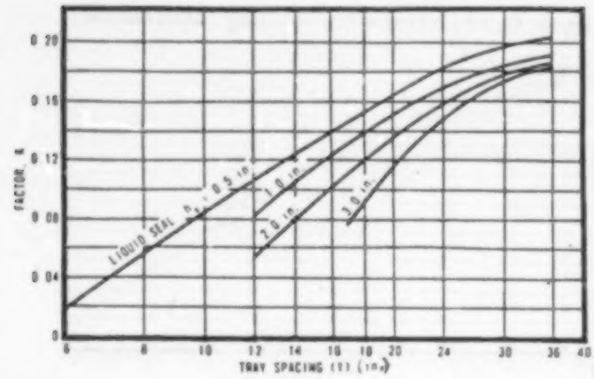

Fig. B-5. Tray-Spacing Constants to Estimate Bubble-Cap Tray Tower's Superficial Vapor Velocity (from ref 4)

The volumetric vapor flow rate is

$$\frac{1534\ \text{lb-moles}}{\text{hr}} \times \frac{18\ \text{lb}}{\text{lb-mole}} \times \frac{26.8\ \text{lb}}{\text{ft}^3} \times \frac{\text{hr}}{3600\ \text{sec}} = 20.6\ \text{cfs.}$$

The cross-sectional area is

$$\frac{20.6\ \text{ft}^3}{\text{sec}} \times \frac{\text{sec}}{5.6\ \text{ft}} = 3.68\ \text{ft}^2.$$

The tower diameter is

$$D = \left[\frac{(4)\ (3.68)}{\Pi}\right]^{0.5} = 2.16\ \text{ft.}$$

4. Tower Height

With 18-in. tray spacing and 44 trays the total height is

$$\left(44 \times \frac{18}{12}\right) + (4 \times 2.16\ \text{ft}) = 74.6\ \text{ft.}$$

5. Tower Pressure Drop

With a ΔP of 3 in. H_2O per tray the total tower presure drop = (3) (44) = 132 in. H_2O.

B. Packed-Column Parameters

The types of calculations used to determine the parameters for packed stripping towers are essentially the same as those used to determine packed absorber parameters (using the same conditions and physical properties that were used to determine plate-stripping-tower parameters); specific sample calculations for packed-stripping-tower parameters are not included.

C. Absorber Inlet Air Duct*

Basis

Approximate linear gas velocity = 4000 fpm; flow-rate = 10,000 cfm at 77°F; duct components = 150-ft duct, 4 ells, 1 butterfly valve, and 1 expansion joint.

---

* The remaining sample calculations will be given for the plate tower example only, as the calculation methods for the packed-column case are the same.

1. **Duct Diameter, D**

$$\frac{10{,}000\ \text{ft}^3}{\text{min}} \times \frac{\text{min}}{4000\ \text{ft}} = 2.5\ \text{ft}^2.$$

$$D = \left[\frac{(2.5)\ (4)}{\pi}\right]^{0.5} = 1.78\ \text{ft (use 20-in. duct)}$$

2. **Pressure Drop**^{7}

$$\Delta P = \frac{3.36 \times 10^{-6}\ fLW^2\ \bar{V}}{d^5}\ ,$$

where

ΔP = pressure drop, psi,

f = friction factor,

L = length of pipe, ft,

W = rate of flow, lb/hr,

$\bar{V}$ = specific volume, ft^3/lb,

d = internal diameter, in.

$$W = \frac{PVM}{RT} = \frac{14.7\ \text{lb}}{\text{in.}^2} \times \frac{10{,}000\ \text{ft}^3}{\text{min}} \times \frac{60\ \text{min}}{\text{hr}} \times 29 \times \frac{1}{10.71} \times \frac{1}{460 + 77} = 44{,}470\ \text{lb/hr},$$

and

$$\bar{V} = \frac{RT}{PM} = \frac{10.71 \times (460 + 77)}{14.7 \times 29} = 13.49\ \text{ft}^3/\text{lb}.$$

To determine f

$$Re = \frac{6.31\ w}{d\mu}\ ,$$

where Re = Reynolds number and μ = viscosity, centipoise.

$$Re = \frac{(6.31)\ (44{,}470)}{(20)\ (0.018)} = 779 \times 10^3.$$

From ref 7, the friction factor, f, is 0.0137.

The values of the equivalent lengths, L, are as follows:

	No.	L/D		L (ft)
Straight-run pipe			=	150.0
Elbows	4	20	=	133.3
Butterfly valve	1	18	=	30.0
Expansion joint (est.)	1	50	=	84.0
Entrance and exit loss	1	109	=	183.0
Total				580.0

$$\Delta P = \frac{(3.36 \times 10^{-6})\ (.0137)\ (580)\ (44470)^2\ (13.5)}{20^5} = 0.22 \text{ psi.*}$$

D. Blower Requirements

Basis

Efficiency = 0.7

$$\text{hp} = \Delta P \frac{\text{lb}}{\text{in.}^2} \times \frac{144 \text{ in.}^2}{\text{ft}^2} \times \text{flow rate } \frac{\text{ft}^3}{\text{min}} \times \frac{\text{min}}{60 \text{ sec}} \times \frac{\text{sec-hp}}{550 \text{ ft-lb}} \times \frac{1}{0.7}\ .$$

$$\text{hp} = 0.00623\ (\Delta P \text{ psi})\ (\text{flow scfm})$$

$$\text{Absorber tower } \Delta P = 72 \text{ in. } H_2O \times \frac{\text{psi}}{27.7 \text{ in. } H_2O} = 2.6 \text{ psi}$$

inlet duct ΔP = 1.0 psi

total ΔP = 3.6 psi

$$\text{hp} = (0.00623)\ (3.6)\ (10{,}000) = 224.$$

E. Pump Requirements

Basis

Efficiency = 0.65, ΔP = 30 psi.

---

*From this calculation the duct pressure drop was found to be relatively small compared to the plate-tower pressure drop, and a constant conservative estimate of 1-psi duct ΔP was used for all cases.

$$\text{Horsepower} = \frac{\text{gpm X psi X 56}}{\text{1715 X .65}} = \frac{156 \text{ X } 30 \text{ X } 1.0}{1715 \text{ X } .65} = 4.2.$$

F. Heat Exchangers

Basis

The criteria used to estimate heat exchanger requirements are summarized in the accompanying combined flowsheet and heat and material balance, Fig. B-6.

2. Feed Effluent Heat Exchanger

$$Q = UA\ \Delta t_m,$$

where

Q = heat transfer rate, Btu/hr,

U = overall heat transfer coefficient Btu/(hr) (ft^2) (°F),

A = heat exchanger surface area, ft^2,

Δt_m = log mean temperature difference, °F.

$$\Delta t_m = \frac{(100 - 77) - (212 - 193)}{\ln \frac{100 - 77}{212 - 193}}.$$

$$Q = \left(\frac{78{,}300 \text{ lb}}{\text{hr}}\right) (193 - 77)\ (1) = 9.1 \text{ X } 10^6 \text{ Btu/hr}.$$

$$A = \frac{Q}{U\Delta t_m} = \frac{9.1 \text{ X } 10^6}{(50.0)\ (20.9)} = 8710 \text{ ft}^2.$$

3. Steam Preheater

$$\Delta t_m = \frac{(267 - 193) - (267 - 212)}{\ln \frac{267 - 193}{267 - 212}} = 64.0\text{°F}.$$

$$Q = \left(\frac{78{,}300 \text{ lb}}{\text{hr}}\right) (212 - 193)\ (1) = 1.5 \text{ X } 10^6 \text{ Btu/hr}.$$

$$A = \frac{Q}{U\Delta t_m} = \frac{1.5 \text{ X } 10^6}{(100)\ (64.0)} = 234 \text{ ft}^2.$$

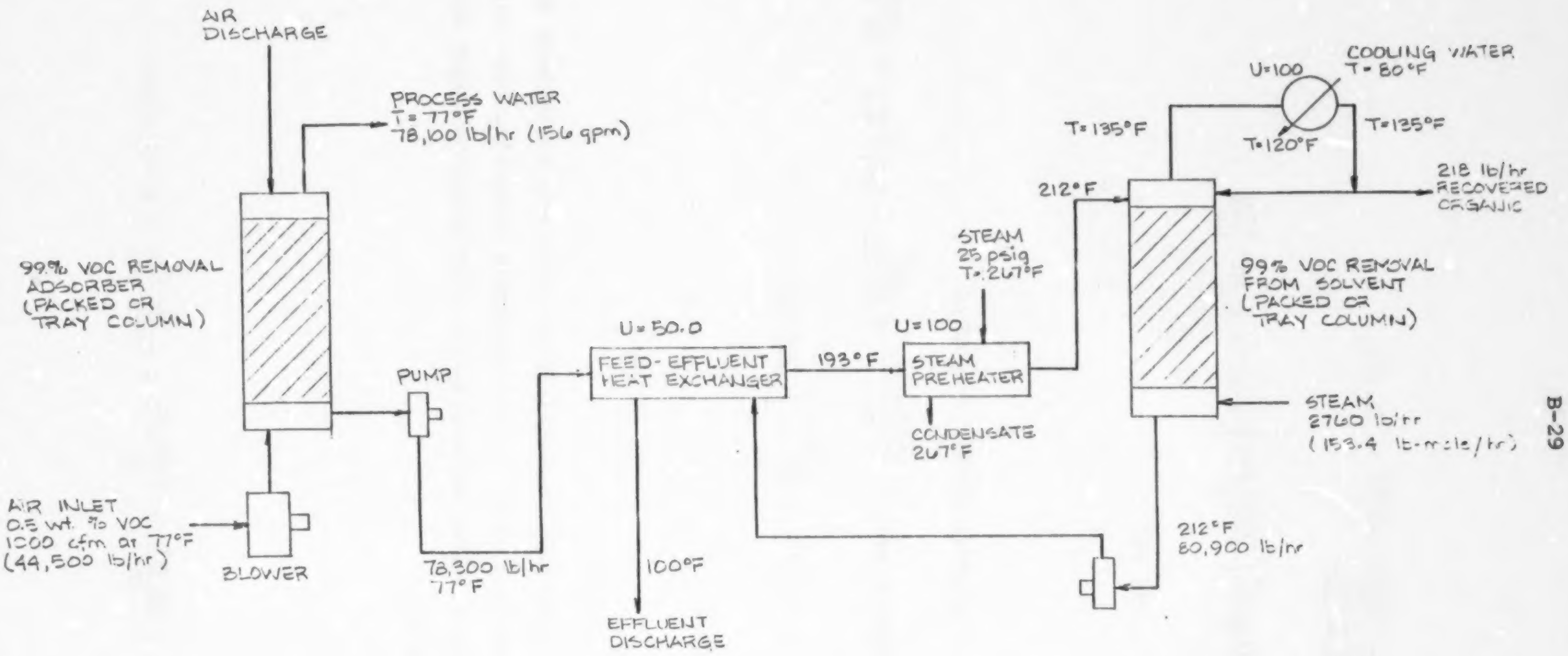
AIR DISCHARGE
PROCESS WATER
T = 77°F
78,100 lb/hr (156 gpm)
99% VOC REMOVAL ADSORBER (PACKED OR TRAY COLUMN)
PUMP
AIR INLET
0.5 wt. % VOC
1000 cfm at 77°F
(44,500 lb/hr)
BLOWER
78,300 lb/hr
77°F
U=50.0
FEED-EFFLUENT HEAT EXCHANGER
100°F
EFFLUENT DISCHARGE
193°F
U=100
STEAM PREHEATER
STEAM
25 psig
T=267°F
CONDENSATE
267°F
212°F
T=135°F
U=100
COOLING WATER
T=80°F
T=120°F
T=135°F
218 lb/hr RECOVERED ORGANIC
99% VOC REMOVAL FROM SOLVENT (PACKED OR TRAY COLUMN)
STEAM
2760 lb/hr
(153.4 lb-mole/hr)
212°F
80,900 lb/hr

Fig. B-6. Sample Flowsheet, Material Balance, and Energy Balance

4. Stripper Condenser

$$\Delta t_m = \frac{(135 - 80) - (135 - 120)}{\ln \frac{135 - 80}{135 - 120}} = 30.8°\text{F}.$$

$$Q = \left(\frac{2760 \text{ lb of steam}}{\text{hr}}\right)\left(\frac{1000 \text{ Btu}}{\text{lb}}\right) = 2.76 \times 10^6 \frac{\text{Btu}}{\text{hr}} \;.$$

$$A = \frac{2.76 \times 10^6}{(100)\ (30.8)} = 896 \text{ ft}^2.$$

G. Piping Requirements

Piping diameter basis = approx. 10-fps velocity.

$$\text{Approximate cross-sectional area} = \frac{80{,}000 \text{ lb}}{\text{hr}} \times \frac{\text{ft}^3}{60 \text{ lb}} \times \frac{\text{hr}}{3600 \text{ sec}} \times \frac{\text{sec}}{10 \text{ ft}} = 0.037 \text{ ft}^2.$$

$$\text{Diameter} = \left[0.037 \text{ ft}^2 \times \frac{144 \text{ in}^2}{\text{ft}} \times \frac{4}{\Pi}\right]^{0.5} = 2.6 \text{ in.}$$

(Use 3-in. sch. 40 pipe.)

H. Capital Cost Estimates

Capital costs for all components were estimated from the parameters as calculated in the previous sections and from IT Enviroscience installed cost data expressed in terms of these parameters. Coat data compiled from previous years were adjusted to a December 1979 basis.

II. Annual Cost

A. Process Water

Basis

$0.25/1000 gal

$$\text{Annual Cost} = \frac{156 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{8760 \text{ hr}}{\text{yr}} \times \frac{\$0.25}{1000 \text{ gal}} = \$20{,}500/\text{yr}.$$

B. Electricity

Basis

$0.03/kWh.

Total hp required = 224 (blower) + 4.2 (pump) = 228.

$$\text{Annual cost} = 228\text{ hp} \times \frac{8760\text{ hr}}{\text{yr}} \times \frac{\text{kW}}{1.341\text{ hp}} \times \frac{\$0.03}{\text{kW-hr}} = \$44{,}700/\text{yr.}$$

C. Wastewater Treatment

Basis

1 lb of BOD/lb of organics in wastewater; 0.05 wt % VOC in untreated air; 99.0% VOC removal in absorber; 99% organic removal in stripper.

Treatment cost = $25/1000 gal + $0.10 lb/BOD.

$$\text{BOD cost} = \frac{44{,}500\text{ lb of air}}{\text{hr}} \times \frac{8760\text{ hr}}{\text{yr}} \times 0.0005 \times 0.99 \times 0.01 \times \frac{\$0.10}{\text{lb}} = \$190/\text{yr.}$$

$$\text{Wastewater cost} = \frac{80{,}900\text{ lb}}{\text{hr}} \times \frac{\text{gal}}{8.33\text{ lb}} \times \frac{8760\text{ hr}}{\text{yr}} \times \frac{\$0.25}{1000\text{ gal}} = \$21{,}270/\text{yr.}$$

Total annual treatment cost = $21,270 + $190 = $21,460/yr.

D. Steam Cost

Steam Requirements

$$Q = Wc_p\,\Delta t = \frac{78{,}300\text{ lb}}{\text{hr}} \times 1.0 \times (212 - 193) = 1.48 \times 10^6\,\frac{\text{Btu}}{\text{hr}}\,.$$

$$\text{Steam required} = \frac{1.48 \times 10^6\text{ Btu}}{\text{hr}} \times \frac{\text{lb}}{1000\text{ Btu}} = 1.48 \times 10^3\,\frac{\text{lb}}{\text{hr}}\,.$$

Stripper = 2760 lb/hr.

Steam Preheater

$$\text{Total steam requirements} = 1.48 \times 10^3 + 2.76 \times 10^3 = 4.24 \times 10^3\,\frac{\text{lb}}{\text{hr}}\,.$$

$$\text{Annual cost} = \frac{4.24 \times 10^3\text{ lb}}{\text{hr}} \times \frac{8760\text{ hr}}{\text{yr}} \times \frac{\$2.50}{1000\text{ lb}} = \$92{,}900/\text{yr.}$$

E. Cooling Water

Basis

$0.10/1000 gal

Cooling water requirements for stripper condenser:

$$W = \frac{Q}{c_p\Delta T} = \frac{2.76 \times 10^6\text{ Btu}}{\text{hr}} \times \frac{\text{lb °F}}{1\text{ Btu}} \times \frac{1}{(120 - 80)\text{ °F}} = 6.9 \times 10^4\text{ lb/hr.}$$

$$\text{Annual cost} = 6.9 \times 10^4 \ \frac{\text{lb}}{\text{hr}} \times \frac{\text{gal}}{8.33 \text{ lb}} \times \frac{8760 \text{ hr}}{\text{yr}} \times \frac{\$0.10}{1000 \text{ gal}} = \$7260/\text{yr.}$$

F. Operating Labor

Basis

$15/man-hour; 25% of one operator's time required.

$$\text{Annual cost} = \frac{8760 \text{ hr}}{\text{hr}} \times \frac{\$15}{\text{hr}} \times 0.25 = \$32{,}900/\text{yr.}$$

III. Cost Effectiveness

Cost effectiveness is defined as the net annual cost per unit (Mg) of VOC emissions removed.

Basis

10,000 cfm of air containing 0.05 wt % VOC; 99% VOC removal by absorber system; $0.10/lb recovery credit for recovered VOC.

From Table A-8, the net annual cost is $495,000.

The annual VOC removed is:

$$44{,}500 \ \frac{\text{lb of air}}{\text{hr}} \times 0.0005 \ \frac{\text{lb of VOC}}{\text{lb-air}} \times 0.99 \times \frac{8760 \text{ hr}}{\text{yr}} \times \frac{\text{Mg}}{2200 \text{ lb}} = 87.7 \ \frac{\text{Mg}}{\text{yr}}$$

and the cost effectivenss is $\frac{\$495{,}600}{87.7 \text{ Mg}} = \$5650/\text{Mg}$.

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